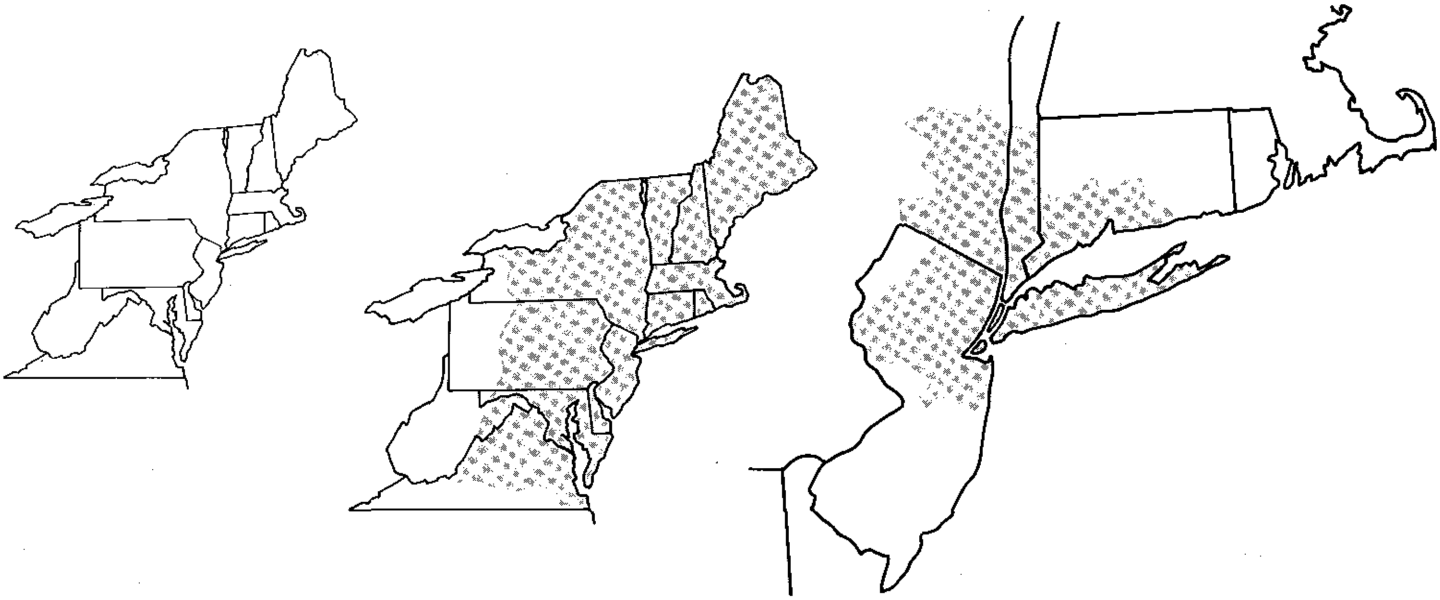
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

AN OPPORTUNITY FOR THE FUTURE: INTEGRATED WATER SUPPLY - POWER GENERATION - WASTEWATER MANAGEMENT - LAND USE CONTROL



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DEPARTMENT OF THE ARMY
NORTH ATLANTIC DIVISION, CORPS OF ENGINEERS
90 CHURCH STREET
NEW YORK, N. Y. 10007

IN REPLY REFER TO

NADPL-S

NOTICE

This report is one in a series of studies to be undertaken in connection with the Northeastern United States Water Supply Study authorized under Public Law 89-298, and assigned to the Division Engineer, North Atlantic Division, U.S. Army Corps of Engineers, for accomplishment.

This report evaluates the technical feasibility of integrating water supply with power plant cooling and wastewater management, with particular emphasis placed on heat transfer to wastewater treatment processes and land disposal of heated wastewater effluent for the purpose of effluent renovation and managing groundwater reservoirs. The techniques of heat transfer, wastewater treatment and disposal are identified and analyzed from a technical viewpoint. Alternative methods of beneficially utilizing the waste heat from the power generating facility are identified and analyzed. Preliminary determination of water supply and environmental quality impacts and economic costs and benefits of integrated management systems are presented. Potential benefits and possible problems resulting from the development of an integrated management system on Long Island, N.Y., are discussed. A project to demonstrate technical feasibility and impacts of a joint management system is described.

The program and policies described in this report are being appropriately considered in the study of regional water supply for the Northern New Jersey-New York City-Western Connecticut Metropolitan Area.

Department of the Army
North Atlantic Division, Corps of Engineers

AN OPPORTUNITY FOR THE FUTURE: INTEGRATED WATER SUPPLY-POWER GENERATION - WASTEWATER MANAGEMENT - LAND USE CONTROL

Contract No. DACW52-73-C-0009
December 1973

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COMPUTER APPLICATIONS

March 14, 1974

Major General R. H. Groves
Division Engineer
North Atlantic Division
Corps of Engineers
Department of the Army
90 Church Street
New York, N. Y. 10007

RE: Contract No. DACW52-73-C-0009

Dear General Groves:

In accordance with the terms and conditions of the Supplementary Scope of Services of the referenced contract, we have examined the feasibility and potential benefits of integrated systems for power plant cooling, wastewater treatment and disposal and water supply management.

Based primarily on existing and reported information, we have concluded that several strong technical linkages can be developed between cooling, wastewater and water supply management. Integrated systems which incorporate such linkages could realize significant economic, environmental and regional benefits. The systems are characterized by technological uncertainties, however, which can only be resolved by programs of further study and field-scale demonstration.

We would like to acknowledge the cooperation of the North Atlantic Division, Corps of Engineers staff during the execution of the project.

Dr. Douglas A. Haith of our organization served as project manager of the study.

Very truly yours,

Thomas P. Quirk, P.E.

TPQ/ld

PREFACE

NORTHEASTERN UNITED STATES WATER SUPPLY STUDY (NEWS)

During the major drought in the northeastern part of the United States in the early 1960's, the Congress recognized that the Federal Government had a major role to play in the solution of water supply problems.

The 89th Congress enacted Public Law 89-298 on October 27, 1965. Title I thereof authorized the Secretary of the Army, acting through the Chief of the Army Corps of Engineers, to cooperate with the various Federal, state, and local agencies in the preparation of plans to meet the long-term water needs of the northeastern United States. (A copy of the Title I legislation is shown on page ii).

Specific features of the legislation related to this study include the provision that the plans developed "may provide for the construction, operation and maintenance by the United States of a system of major reservoirs" and that "such plans shall provide for appropriate financial participation by the states, political subdivisions thereof, and other local interests."

Under authorization of the Act, the Corps of Engineers, North Atlantic Division, has established a NEWS Study Group, which has conducted a series of studies to determine the water supply needs of the area, to identify alternative water supply projects to meet these needs, and to identify institutional and cost-sharing options relative to Federal, state, and local efforts required for the implementation of the water supply projects.

The following report examines the feasibility of integrated management systems for power plant cooling, wastewater treatment and disposal, and water supply for the Northern New Jersey - New York City - Western Connecticut metropolitan area.

Public Law 89-298
89th Congress, S. 2300
October 27, 1965

An Act

Authorizing the construction, repair, and preservation of certain public works on rivers and harbors for navigation, flood control, and for other purposes.

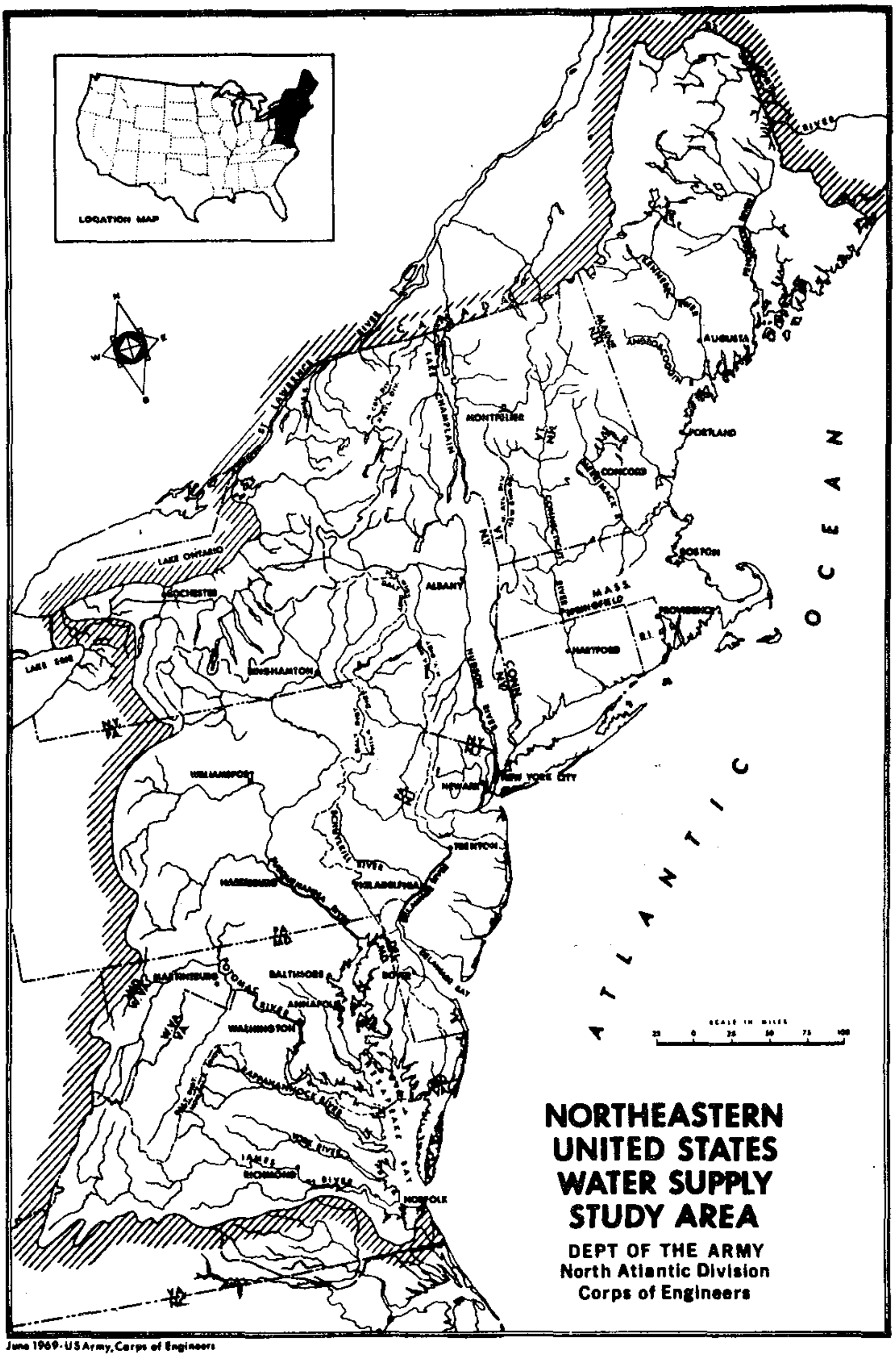
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

TITLE I—NORTHEASTERN UNITED STATES WATER SUPPLY

SEC. 101. (a) Congress hereby recognizes that assuring adequate supplies of water for the great metropolitan centers of the United States has become a problem of such magnitude that the welfare and prosperity of this country require the Federal Government to assist in the solution of water supply problems. Therefore, the Secretary of the Army, acting through the Chief of Engineers, is authorized to cooperate with Federal, State, and local agencies in preparing plans in accordance with the Water Resources Planning Act (Public Law 89-80) to meet the long-range water needs of the northeastern United States. This plan may provide for the construction, operation, and maintenance by the United States of (1) a system of major reservoirs to be located within those river basins of the Northeastern United States which drain into the Chesapeake Bay, those that drain into the Atlantic Ocean north of the Chesapeake Bay, those that drain into Lake Ontario, and those that drain into the Saint Lawrence River, (2) major conveyance facilities by which water may be exchanged between these river basins to the extent found desirable in the national interest, and (3) major purification facilities. Such plans shall provide for appropriate financial participation by the States, political subdivisions thereof, and other local interests.

(b) The Secretary of the Army, acting through the Chief of Engineers, shall construct, operate, and maintain those reservoirs, conveyance facilities, and purification facilities, which are recommended in the plan prepared in accordance with subsection (a) of this section, and which are specifically authorized by law enacted after the date of enactment of this Act.

(c) Each reservoir included in the plan authorized by this section shall be considered as a component of a comprehensive plan for the optimum development of the river basin in which it is situated, as well as a component of the plan established in accordance with this section.



June 1969 - US Army, Corps of Engineers

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CHAPTER I - INTRODUCTION

The history of water-resource development in the United States includes numerous examples of multipurpose management. The most striking of these have been the construction and operation of reservoirs on western rivers for a range of purposes including flood control, irrigation and hydroelectric power generation. However, multipurpose water-resource management is infrequently applied in areas of water surplus such as the Northeastern United States, or in situations in which water is a secondary input to or, output from, the management of other resources. Examples of the latter are utilization of large quantities of water for cooling by nuclear and fossil-fueled power plants and the management of wastewater discharges for augmentation of surface or ground water supplies. In rapidly urbanizing areas, a number of factors are combining to make multipurpose management of water and other resources such as energy and land a necessity:

1. External Costs: As a region becomes more densely populated, the external impacts of any resource management project on the region and on other projects becomes more severe.

2. Availability of Large Parcels of Suitable Vacant Land: Reservoirs, electric power plants, and even on a smaller scale, sewage treatment plants, are increasingly difficult to locate in developing areas.

3. Inability of the Natural Environment to Assimilate Increased Quantities of Pollution: In remote areas, a power plant could discharge heated effluent without undo ecological damage and septic tanks or primary and secondary sewage treatment plants could provide wastewater control which would avoid adverse environmental effects. However, as increased urbanization results in additional discharges into bodies of fixed assimilative capacity, environmental degradation will occur.

4. Availability of High-Quality Water Supply: The combination of heavy industrial and municipal water use and degradation of surface and ground water supplies in urbanizing areas tends to reduce the quality and quantity of water traditionally considered suitable for various purposes.

The above problems are particularly evident in the Northeast, and even though the water resources of the area are abundant, the joint, multipurpose management of water, energy and land resources offers potential benefits for a range of economic, environmental and regional objectives. The purpose of this study is to investigate the technical feasibility and evaluate the economic, environmental and regional impact of integrated management systems for power plant cooling and wastewater treatment and disposal. Special attention is focused on the water supply impact of alternative systems, and on the use of land application as a mechanism for wastewater renovation. To the extent possible, the analyses and the results of the study have been given general applicability to coastal areas of the Northeastern United States. In order to give more specific details of system characteristics, the Suffolk County area of Long Island has been selected as an illustrative setting for the integrated systems.

A. GENERAL CHARACTERISTICS OF COOLING AND WASTEWATER MANAGEMENT SYSTEMS

Power Plant Cooling

Electric power plants which operate on a steam generation-condensation cycle function at efficiencies on the order of 30% and 40% for nuclear and fossil-fueled plants, respectively. A nuclear plant dissipates approximately twice as much energy in waste heat as it converts into electricity. Most of this heat is contained in cooling water which is used to condense steam after it leaves the plant turbines subsequent to return to the boilers. Waste heat is dissipated from the cooling water to the environment either through direct cooling water discharge to surface water bodies or by evaporative cooling systems such as towers and ponds.

The rejection of large quantities of heat from electric power plants represents a major loss of energy resources. Thermodynamic limitations impose a constraint on the improvement of power plant efficiencies, and the only practical means of significant control of energy losses is through the beneficial use of the waste heat contained in the cooling water. This heat is of relatively low grade, since the temperature difference between the heated cooling water and the natural environment is typically between 10 and 30°F. Although such temperatures are generally considered to be too small to provide economical heat utilization, several types of beneficial use are possible. These include thermal enhancement of wastewater treatment, aquaculture and various agricultural applications, all of which are investigated in this study.

Waste heat discharges from power plants are also associated with a wide range of environmental problems. A traditional source of cooling water has been surface water bodies such as rivers, lakes, estuaries and bays. Large quantities of water (700-1000 million gallons per day in the case of a nuclear plant) are removed from the water bodies for cooling purposes and then discharged at temperatures of 10 to 30°F above ambient levels. The resulting thermal pollution can be harmful to aquatic life. In addition various animal and plant species may be destroyed in the intake structures or by thermal shock received during passage through condensers. Damage to aquatic fauna may also result from their inability to adjust to lowered temperatures or cold shock when power facilities are shut down for repairs.

The principal alternatives to direct discharge or once-through cooling systems are closed-cycle or recirculating evaporative systems, such as cooling towers and ponds. While adverse effects on receiving bodies are avoided by such means, problems of fogging, drift and possible thermal climatic effects are present. In addition, cooling towers are massive structures with severe visual impact and often noisy operating conditions. Cooling ponds require substantial land areas (two to three square miles for a nuclear plant) which is available in rapidly developing areas only at a high cost. Finally, evaporative towers and ponds are not completely closed-cycle. Water is periodically added and removed for "blow-down" to prevent buildup of dissolved solids. Blow-down water must be disposed of, frequently to receiving waters. Evaporative water losses must also be replaced, and make-up water for blow-down and evaporative losses may typically be 2-3% of the recirculating cooling water. If the cooling system uses fresh water, this consumptive use may have a direct impact on an area's water supply.

Although the above problems are relevant to power plant siting in any locale, they become especially critical in the Northeast coastal area. The region's power demands require a continued increase in electric generating capacity, but high population density, limited vacant land areas, marginal ability of the environment to receive additional wastes, and diminished water supplies dictate the need for great care in site selection and design of cooling systems.

Wastewater Management

A wastewater management system consists of collection, treatment and disposal facilities. In rural areas and small villages each dwelling typically has its own complete system in the form of a septic tank or cesspool. Suburbanization frequently requires abandonment of these systems due to excessive ground water pollution, and municipal collection (sewerage) facilities transport wastewaters to a central treatment plant. Although substantial economies of scale are realized in the construction and operation of treatment systems, the dispersed population in suburban areas produces high unit collection costs, thus imposing economic limits on the centralized treatment of suburban wastewaters. The urban area is the most economical setting for centralized wastewater management, since unit collection costs are moderated by concentrated population and substantial wastewater volumes permit construction of large treatment plants with their attendant economies of scale.

Wastewater must be disposed of after treatment, however, and the typical disposal mechanism has been discharge to surface and ground waters. As one moves along the spectrum from rural to suburban to urban setting, the problems associated with disposal become more acute.

The widely distributed leaching of wastewater from septic tank drainage and cesspools in rural areas generally constitutes a relatively minor threat to water quality. Moreover, such leaching recharges ground water supplies, thus returning water to potential further use. In more developed (suburban) areas, municipal collection and centalized treatment concentrate significant volumes of wastewater at one location. When disposal is to a surface body of water such as a river or lake, significant organic pollution may result and wastewater nutrients such as nitrogen and phosphorus may cause eutrophication. Problems can be minimized by costly advanced waste treatment techniques for organic matter and nutrient removal. Alternative disposal may be to ground water by means of recharge basins or wells. Advanced treatment may again be required, particularly to prevent nitrogen pollution of ground waters. A third option for suburban areas is to distribute wastewaters by land application to a soil/plant ecosystem. This "living filter" of plants, soil particles and microorganisms, can, with proper design and management, renovate wastewater to a very high quality. Except where discharge is to a saline environment, the above alternatives conserve the wastewaters for further use for water supply.

A coastal city's options for wastewater disposal are generally quite limited. Discharge to an estuary or bay is frequently considered the only feasible approach and these discharges may degrade water quality to an extent that the recreation and scenic value of the city's river and ocean frontage and beaches is severely reduced and the aquatic life of the area is jeopardized. The use of advanced waste treatment or transmission of wastewaters to non-urban areas for land application will control these problems, but only at great expense. Discharge of sewage effluents to saline waters will, of course, prevent the potential use of wastewater for water supply.

In summary, as a coastal area becomes developed, wastewater management becomes more expensive and the control of environmental problems associated with wastewater becomes more difficult and expensive. The impact of wastewater management on water supply is also increasingly severe. From the rural setting, in which wastewater replenishes water supplies, impacts progress to the large coastal city, for which ocean disposal prevents any further water supply use of wastewater.

Water Supply

Water supply needs of Northeastern coastal areas have typically been satisfied by wells and upstream reservoir systems. Since the region's water resources are abundant, water conservation practices traditionally received little attention until the 1960's drought. Severe shortages occurred during this period, with lowered water tables resulting in salt water intrusion into well fields and reservoir elevations reaching their lowest levels of record. Northeastern water supply deficiencies have been extensively documented and a variety of planning measures and institutional arrangements have been proposed (1, 2, 3, 4). Although the specific nature of the water supply problem varies with locale within the region, some generalization is possible. First of all, although the gross quantity of ground and surface water vastly exceeds present and future water supply needs, the quality of much of this water limits its suitability for water supply. Secondly, localized deficits between supply and demand can in many cases be met only with regional water transfers.

Since both power plant cooling and wastewater management impact on water supplies, it follows that in much of the Northeast, water supply should be considered at least a secondary objective in the siting of power plants and in the selection of wastewater disposal alternatives. Cooling systems which have low consumptive water use and wastewater disposal methods which augment water supplies realize tangible regional benefits which should be added to the primary benefits of energy production and water quality enhancement.

B. INTEGRATION OF POWER PLANT COOLING, WASTEWATER MANAGEMENT AND WATER SUPPLY

The rapid development of coastal areas requires that joint management of water, energy and land resources be given serious consideration. Integration offers the potential of reducing the external costs imposed by single-purpose projects on other related projects, and in addition may result in more efficient resource utilization. The key to this management option is the identification of possible technical linkages between the various resource problems. In the case of power and wastewater management, several strong linkages exist. First, the siting requirements for power and sewage treatment plants are not mutually exclusive. Secondly, considerable evidence exists indicating that the addition of heat can significantly enhance the efficiency of wastewater treatment. Waste heat from power plants is a possible source for this enhancement. In addition, consumptive use of water cooling systems provides a linkage with wastewater management by which wastewater may be used as make-up for evaporative cooling.

The environmental and social acceptance difficulties encountered in siting nuclear power plants have been well-publicized. Although an increase in electric generating capacity may be beneficial to a large region, the marginal benefits accruing to the immediate locale of the power plant may be less than the opportunity cost of the site land area to the locality, the possible loss of land values, and the undefined psychic cost of the nearby nuclear power plant. One means of improving the local benefit-cost balance is to utilize the plant site for additional purposes such as wastewater treatment. Moreover, depending on the scale of integration of cooling and treatment, additional benefits may be realized from preservation of open land, control of waste discharges and water supply augmentation.

The use of power plant waste heat for enhancement of wastewater treatment has received considerable attention recently. The New York State Atomic and Space Development Authority has investigated the feasibility of utilizing waste heat in a 50 million gallons per day treatment facility and subsequent distillation of wastewater for water supply use (5). A University of Texas study has proposed the use of a single lake or pond for both cooling and waste treatment use (6). Conceptual systems for the use of waste heat to improve waste treatment have been suggested by Boersma and Rykbost (7) and Oswald (8). A 30 million gallons per day wastewater treatment plant which utilizes waste heat from nuclear power production has been proposed for Rhode Island (9). These studies and proposals are based on knowledge that elevated wastewater temperatures enhance the efficiency of the biological, physical and chemical processes utilized in wastewater treatment. The transfer of waste heat to wastewater treatment represents a conservation of energy which might otherwise be dissipated to the environment as heat, and may permit reduced capital investment in treatment since efficiency improvements should reduce required treatment plant size.

The possible water supply linkages of power plant cooling and wastewater management are varied. Wastewater use for make-up is one possibility, and where wastewater volumes are very large, such flows may be used directly for cooling water. Another possibility, which is investigated in this study, is land application of heated wastewaters to agricultural crops. In this fashion waste heat is used for treatment enhancement and also passes to the growing crop. The heat may benefit the growing plants and water quantities in excess of crop requirements will recharge ground water supplies.

Although a variety of beneficial uses of waste heat may be feasible, major emphasis in this study is on the use of such heat in wastewater treatment. This does not imply that other uses of waste heat would not be beneficial either in place of, or in conjunction with wastewater treatment. Rather, the study orientation is based on the evidently strong technical link between power plant cooling and wastewater treatment and the need to evaluate the technological feasibility and regional impacts of integration.

C. APPLICABILITY TO A SPECIFIC AREA: LONG ISLAND, N. Y.

There are certain drawbacks to the study of resource management systems of general applicability. Such systems may make much sense at the conceptual stage, but attempts at implementation may reveal difficult and unforseen problems. To test the integration methods suggested in the study, systems are evaluated for the Suffolk County area of Long Island. It is important to realize that such a procedure does not limit the management systems to Long Island, but rather ensures that systems are conducive to implementation in a real setting. Characteristics of Long Island which are relevant to the present study are outlined below.

General

Long Island's Nassau and Suffolk Counties (Figure I-1) have followed development patterns similar to other coastal areas near large cities. Nassau's population increased rapidly between 1940 to 1960, with much of the county's open lands being converted to residential use. A similar pattern began in Suffolk County in the 1950's, and substantial growth rates are projected well into the future. By comparison, Nassau population growth moderated significantly in the 1960's reflecting the decreased availability of land suitable for development. Population growth and projections are summarized in Table I-1, and 1970 population densities are shown in Figure I-1.

TABLE I-1

POPULATION GROWTH IN NASSAU AND SUFFOLK COUNTIES (Ref. 3)

	1940	1950	1960	1970	1980
Nassau	406,700	672,800	1,300,200	1,428,800	1,542,000
Suffolk	197,400	276,100	666,800	1,127,000	1,499,000
Total	604,100	948,900	1,967,000	2,555,800	3,041,000

The most recent (1966) land use categories are summarized in Table I-2. Comparison of the two counties indicates that while Nassau has been highly developed for residential use, large quantities of open land still remain in Suffolk. Suffolk's western towns have a high degree of suburban development which characterizes Nassau, but the eastern towns have retained much of the rural nature of an agricultural region.

An indication of land use trends is the decline in vacant and agricultural land in Nassau from 21% in 1956 to 7% in 1966. A similar decline of 82% to 50% was observed in Suffolk from 1961 to 1966 (10). The total agricultural acreage in Suffolk County has declined from 119,000 acres in 1940 to 90,000 acres in 1960 and 60,000 acres in 1972 (11). It is obvious that if present population and land use trends continue, Suffolk County will gradually assume the highly developed character of Nassau. One indication of the magnitude of this development is the projection that Suffolk, which is currently New York State's leading agricultural county, will have no agricultural land use by 1985 (12).

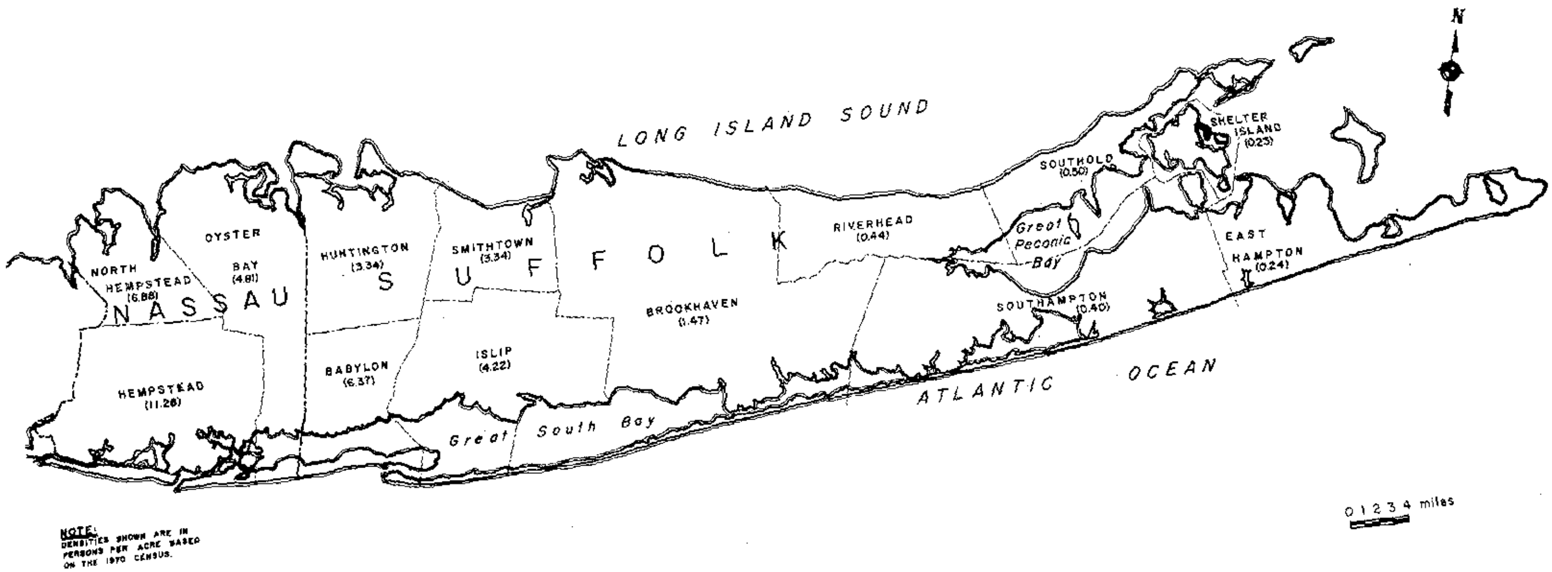

FIGURE I-1

LONG ISLAND TOWNS & POPULATION DENSITIES

TABLE I-2

1966 LAND USE IN NASSAU AND SUFFOLK COUNTIES (Ref. 10)

		Nassau	Suffolk
Residential	(%)	45	14
Commercial, Industrial, Utilities	(%)	6	6
Institutional	(%)	5	4
Recreation	(%)	8	7
Agriculture	(%)	1	9
Roadways	(%)	15	6
Vacant	(%)	7	40
Water	(%)	13	14
Total Area (Acres)		200,949	676,860

The rapid, and to an extent, uncontrolled development of first Nassau and now Suffolk Counties has been a subject of concern to planners and other public officials. Development and land use controls are controversial issues, but there appears to be some agreement that preservation of open lands and agriculture is essential for the maintenance of a reasonable economy and quality of life in Suffolk County (13, 14). The Long Island of the future will exert substantial demands on energy resources and water supply, and will generate increasing quantities of wastes capable of environmental pollution. Thus, any evaluation of the integrated resource management systems outlined in the study must be addressed to these problems. At a second level, however, the compatibility of resources management with the regional objectives of open land and agriculture preservation may be as important as energy, water and environmental conservation.

Long Island Water Supply

The water supply needs of Nassau and Suffolk Counties are provided primarily by two ground water aquifers. An upper glacial aquifer served historically as Long Island's traditional supply source, but salt water intrusion in shoreline areas and pollution from septic tanks and cesspools limit its present use to the less developed central and eastern Suffolk area. The underlying Magothy aquifer is pumped extensively in Nassau and western Suffolk Counties. The excess of pumping over recharge has resulted in salt water intrusion into the Magothy aquifer, particularly in Nassau County. Surface water supply sources are of marginal importance on the Island, and virtually all of the stream flows are attributed to ground water discharge. Natural ground water recharge is essentially the difference between precipitation and evapotranspiration. Average annual amounts of 46" and 22" respectively are used in this study (15), corresponding to an average annual recharge of 24". Outflows from the aquifers include underflow to the ocean, stream flows and pumping for water supply.

Much of the water pumped for water supply is eventually returned to the aquifers, either through leaching of wastewater from septic tanks and cesspools or by return of cooling and industrial process waters by injection wells. As is noted in the following section, existing and proposed sewering will limit wastewater recharge in the future. Water usage in 1970 was estimated to be 212 million gallons per day (mgd) in Nassau and 150 mgd in Suffolk (1). Projected demands for 1980 range from 226-250 mgd for Nassau, and 183-220 mgd for Suffolk (1, 15).

The permissive yield of Long Island aquifers has been estimated in various studies. The term "permissive yield" refers to "the amount of water which can be withdrawn annually without producing an undesired result" (1). There is obviously a great deal of judgement required in defining "undesired" results, but examples include the drying up of surface streams, salt water intrusion, and the reduction of the total amount of water stored in aquifers ("mining" of ground water, thereby reducing the supply available for future use). The general uncertainty surrounding such factors as evapotranspiration and underflow makes the estimation of ground water yields a risky matter. Nevertheless, current estimates are approximately 150 mgd for Nassau County (1) and 441 mgd for Suffolk County (15). These estimates do not consider additions from artificial recharge by wastewaters and cooling waters.

The current pumping in Nassau County is more than the County's permissive yield. Although artificial recharge does mitigate this excess pumping somewhat, "undesired results" have certainly occurred, namely, the intrusion of salt water into the Magothy aquifer.

The Suffolk County yield is more than double the projected 1980 demands. However, the water supply picture is not entirely bright. Yields are not distributed uniformly throughout the county. A comparison of permissive yields and projected aquifer pumpage is given in Table I-3 for Suffolk towns. Although this pumpage includes industrial cooling and process use which returns water to the aquifers, the projected withdrawals may result in a number of localized supply and environmental problems. For example, increased pumpage will tend to decrease the amount of fresh water reaching Long Island Sound and the South bays. The resulting salinity increases may have adverse effects on the ecologies of these areas.

Plans for water supply development for 1980 differ markedly in the two counties. Proposals for Suffolk County indicate a general continuation of spread well field development, with increased reliance on the deeper Magothy aquifer. Consolidation of water supply systems and importation of water from surplus areas to deficient areas is included in proposed plans. Unit costs to the various towns range from $0.23 to $0.47 per thousand gallons. An exception is water supply provision to ocean beach lands which is estimated at $0.87 per thousand gallons (15).

TABLE I-3

ESTIMATED AQUIFER YIELDS AND 1980 PUMPAGE FOR SUFFOLK COUNTY TOWNS (Ref. 15)

Town	Permissive Sustained Yield (mgd)	1980 Aquifer Pumpage (mgd)
Babylon	30	34
Huntington	55	39
Islip	61	38
Smithtown	32	20
Brookhaven	157	46
Riverhead	34	15
Southampton	50	13
East Hampton	11	6
Southold &Shelter Island	11	1
Total	441	212

Nassau County's future demands can be met only by major aquifer recharge by wastewater, mining of the Magothy aquifer, or by regional programs which may include water transfers from Suffolk County. The use of storm water recharge basins in the center third of the island has been suggested for discharge of highly treated wastewater for ground water recharge. A 94 mgd recharge system would cost approximately $0.40 per thousand gallons of water added to the aquifer (16). This estimate includes the advanced treatment of wastewater which has already undergone secondary treatment, but does not include the wells and pumping required to remove the water from the aquifer for water supply. A 53 mgd water mining program for Nassau County is estimated at $0.20 per thousand gallons (16), exclusive of local distribution costs. Alternatives for transfer of 50 and 100 mgd from Suffolk to Nassau Counties would cost $0.27 and $.25 per thousand gallons, respectively (3), again exclusive of local distribution costs.

Wastewater Management on Long Island

Long Island wastewater management is currently in transition from a general reliance on septic tanks and cesspools for domestic wastes to the use of sanitary sewers and sewage treatment plants. As of 1970, only 50% of Nassau and 7% of Suffolk populations were served by sewers (17). Although the present septic tank and cesspool discharges have resulted in significant recharge for the region's ground water supplies, these same discharges have also severely polluted the aquifers, particularly in Nassau and western Suffolk Counties. To control this pollution, federal construction grants have been authorized for nineteen wastewater projects in Nassau and nine projects in Suffolk. These and other proposed projects will provide for secondary level treatment and discharge of the treated wastewaters to the island's bays and estuaries (17).

The connection between wastewater management and water supply is particularly evident on Long Island. One motivation for the above projects is the protection of the Island's ground water supplies from pollution. However, ocean disposal will eliminate a large source of ground water recharge, thus decreasing ground water yields. Eutrophication of Long Island Sound and the south bays may also occur due to the nutrients contained in the waste discharges.

Recharge of aquifers with high-quality wastewater effluent is considered to be the long-term solution to the above problems (17). Research is being conducted at the Bay Park treatment plant on deep well injection of advanced treated wastewaters (18). Other options for recharge include the use of recharge basins similar to those currently used for storm waters on the Island and spray irrigation of agricultural crops. The latter alternative is currently being investigated at Brookhaven National Laboratories (19). None of the above disposal alternatives are presently included in the major existing or proposed wastewater management systems on Long Island. Sewer districts are in existance in both counties. Major flows are indicated in Figure I-2.

Electrical Energy Production on Long Island

The electric power needs of Nassau and Suffolk Counties are supplied almost exclusively by the Long Island Lighting Company (LILCO). Installed generating capacity reached 3,174 megawatts in 1972 (20), and consists primarily of fossil-fueled steam generation and a small number of gas turbine and diesel plants for peak power demands. Locations of existing and proposed LILCO plants are shown

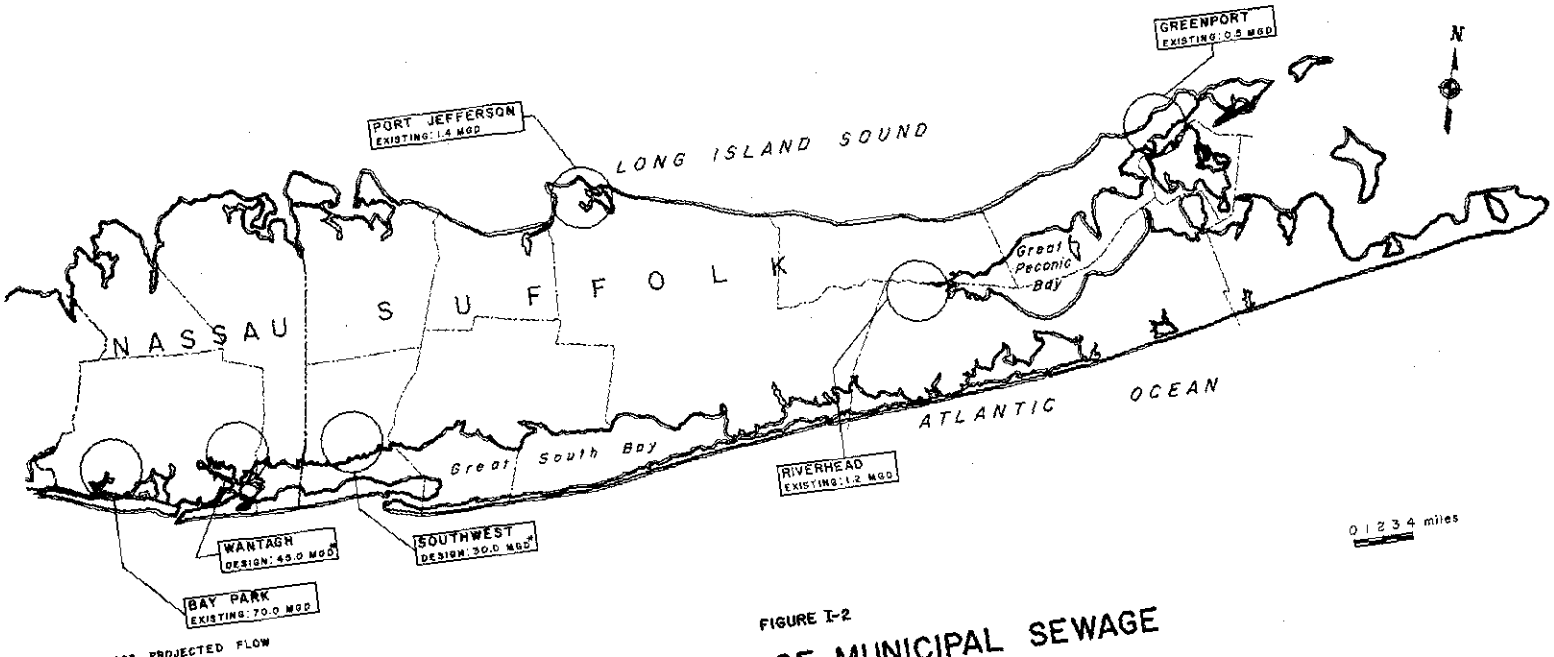

FIGURE I-2

MAJOR SOURCES OF MUNICIPAL SEWAGE ON LONG ISLAND in Figure I-3. The major steam plants use Long Island Sound water for once-through cooling. No construction of large steam plants on Long Island's south shore has been contemplated by LILCO, since costly outfalls would be necessary and fuel transport would be difficult (21). Nuclear plants with evaporative cooling systems may be possible on the south shore, however.

The Atomic Energy Commission has issued a construction permit for Long Island's first nuclear plant, a 820 megawatt unit at Shoreham. A three-year hearing (the longest in AEC history) preceded the issuance of the permit, reflecting the considerable controversy surrounding nuclear plant siting on Long Island. The total time to plan, build, and bring into operation a nuclear power plant on Long Island is in the neighborhood of 10-11 years (21). A substantial portion of this time is spent in hearings for resolution of safety and environmental concerns.

Future electric power demands for Nassau and Suffolk Counties are somewhat uncertain, since energy conservation measures may mitigate against continuation of past trends. The New York State Atomic and Space Development's projected generating requirements of 4740 and 8740 megawatts in 1980 and 1990 respectively for Nassau and Suffolk Counties (5) are based on extrapolations of past trends, and should perhaps be considered upper limits.

D. STRUCTURE OF THE STUDY

The present study has several broad objectives:

(i) Evaluation of the technical feasibility of integrating power plant cooling and wastewater management with particular emphasis placed on heat transfer to wastewater treatment processes and land disposal of heated wastewater effluent.

(ii) Preliminary determination of water supply, environmental quality and economic benefits and costs of integrated management systems.

(iii) Evaluation of the regional impact resulting from the development of an integrated cooling/wastewater management system on Long Island.

To accomplish these objectives a systems analysis of the cooling/wastewater problem was performed. The general integrated system which was studied is shown in Figure I-4. A cooling/wastewater management system is seen as having three components: (i) power plant cooling or rejection of waste heat from the power plant condensers, (ii) thermally enhanced wastewater treatment, and (iii) wastewater disposal. Alternatives are possible for each component; thus, for example, disposal alternatives include land application, ocean discharge and use of wastewater for make-up in evaporative cooling systems.

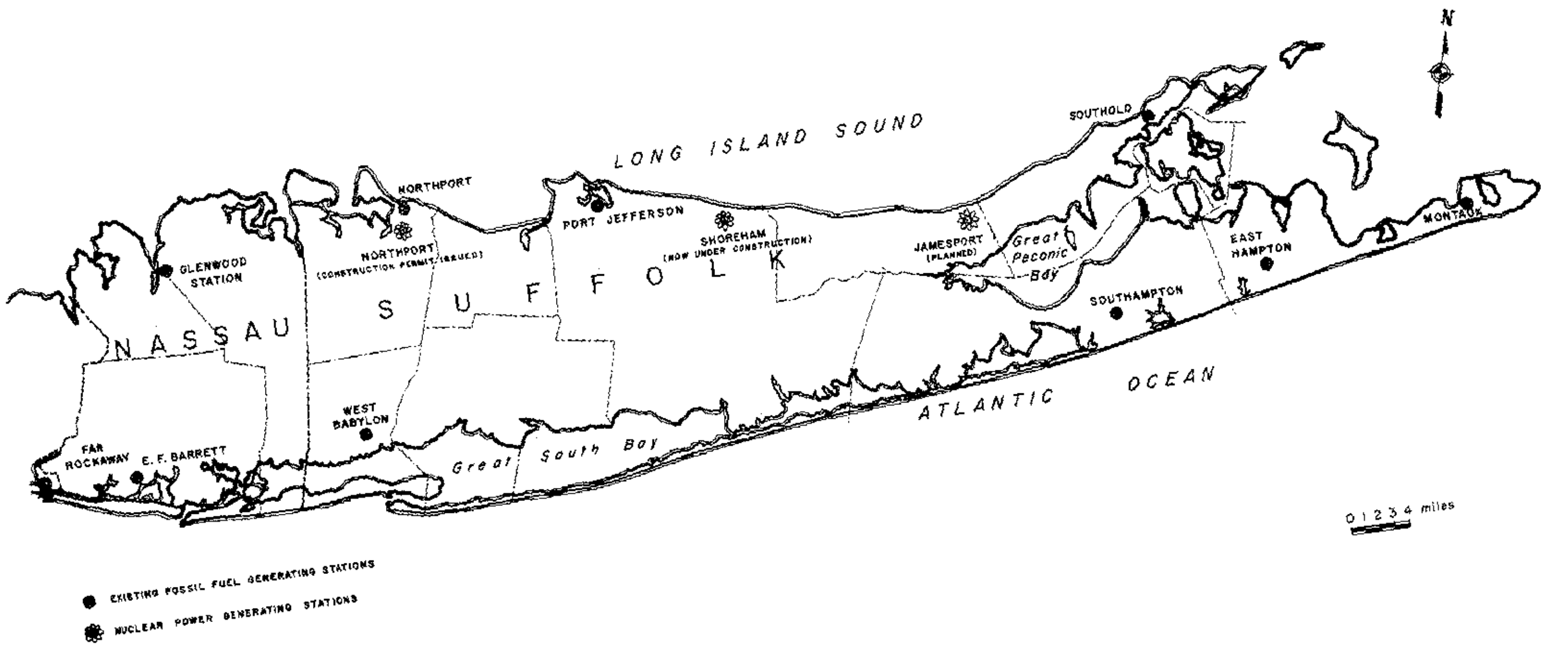

FIGURE I-3

LONG ISLAND POWER PLANTS

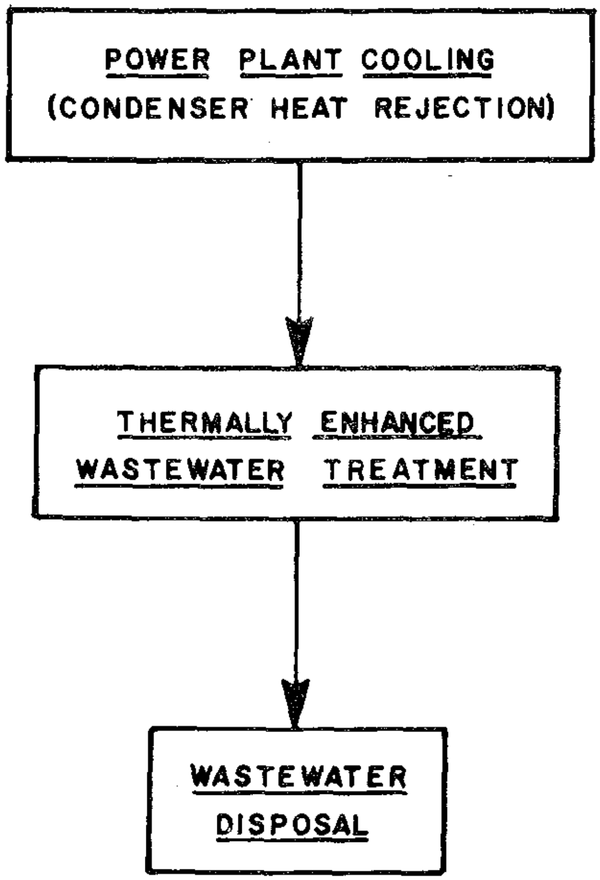

FIGURE I-4

COMPONENTS OF AN INTEGRATED POWER PLANT COOLING-WASTEWATER MANAGEMENT SYSTEM

As reported in succeeding chapters, the study was executed in a sequential fashion. Alternatives for each of the system components were first analyzed (Chapters II, III, IV) and subsequently certain of the alternatives were combined into integrated systems. The technical feasibility of these systems was examined and preliminary estimates of system impacts were made (Chapter V). One management system was selected and evaluated for its regional impact on Long Island (Chapter VI). Finally, recognizing the technological uncertainties which characterize the joint management of cooling and wastewater treatment systems, a program of further study and demonstration is indicated (Chapter VII).

The analyses reported herein are limited to an identification of potential problem areas and impacts associated with both the components and the total system of cooling/wastewater management. No detailed designs or cost estimates have been made and existing literature has been relied on to the extent possible. In certain cases, particularly relating to technical performance, detailed information did not exist, and specific analyses were required. The details and assumptions of these analyses are indicated in the Appendix. To facilitate comparison with other studies undertaken as part of The Northeastern United States Water Supply Study, an ENR index of 1400 was used for all cost estimates.

CHAPTER II - POWER PLANT COOLING

A limited number of alternatives are available for power plant cooling, which is defined in this study as the removal and dissipation of waste heat rejected at the power plant condensers. In the Northeast, these alternatives are once-through cooling using ocean or other surface waters, and three types of evaporative cooling systems: wet towers, spray ponds or cooling ponds. Dry cooling towers and combination wet-dry towers are additional possibilities, but have not yet seen application to large nuclear power plants (22). The application of once-through and evaporative cooling systems to nuclear power plants in the Northeast is discussed in this chapter. In addition, a variety of beneficial uses of power plant waste heat are reviewed.

A. ALTERNATIVE COOLING SYSTEMS

A comparison of costs, environmental impacts, and consumptive water use of cooling alternatives is necessary for an evaluation of integrated cooling and wastewater management. Such comparisons are difficult, however, since the characteristics of a plant site will influence the cooling costs, environmental impacts, and evaporative water losses, and the various cooling methods will effect overall power plant efficiencies. Lost efficiency is a real monetary cost which should be included in the costs of a cooling system.

In order to facilitate system comparisons a "standard" 1100 megawatt (MW) nuclear power plant was selected. This plant is considered to have a nominal efficiency of 32%, indicating that 10,700 BTU of heat are required to produce one kilowatt-hour of electricity. A cooling water flow of approximately 850 million gallons per day is required to remove 7.5 billion BTU per hour of waste heat from the power plant condensers. The temperature differential between the cooling water entering and leaving the condensers is 25°F.

Once-Through (Open-Cycle) Cooling

Once-through cooling is the most common form of power plant cooling in the Northeast. It's selection has been based on low capital cost and minimal loss of power plant efficiency compared to other systems, as well as the availability of surface bodies of waters (rivers, lakes, and coastal waters). By utilizing cool water from a natural water body and returning the water at an elevated temperature, the water body is relied upon for the assimilation and dissipation of waste heat. The process is somewhat analogous to the discharge of sewage into surface waters and the subsequent degradation and stabilization of wastes by natural processes in the water body.

The environmental affects on a receiving water can be quite severe with once-through cooling. The physical movement of large quantities of water can result in entrainment and impingement of fish and other organisms in intake structures, and induced circulation currents may produce changes in the aquatic ecology near intakes and outfalls. Moreover, when the chemical and biological characteristics of the intake area (such as the hypolimnium or bottom zone of a lake) differ markedly from the characteristics of the outfall area (again, for a lake, the epilimnium or surface zone) the resulting mixing may have unpredictable ecological impact. There are two principal thermal impacts of once-through cooling. The large artificial heat input to the water body can result in fish kills due to high temperatures and lowering of dissolved oxygen concentrations. Conversely, aquatic life which has adjusted to warm water temperatures may be harmed by the colder (natural) conditions that result from power plant shut-downs. In addition, the small plants and animals which pass through the condensers may be destroyed, thus interfering with life and food cycles in the receiving waters.

Adverse environmental impacts can be mitigated, to an extent, by suitable design of intake and outfall structures and by the use of elaborate diffusers to disperse heat at outfalls. Limitations on such measures are similar to those applicable to other types of waste discharges to aquatic bodies. As the waste loading (thermal pollution, in this case) becomes larger relative to the water body's fixed assimilative capacity, adverse environmental effects become increasingly difficult to prevent.

Evaporative (Closed-Cycle) Cooling

In addition to water, a second direct disposal medium for much of man's wastes is the atmosphere. The ability of the atmosphere to assimilate waste heat without adverse environmental effects is sufficiently large for it to be an attractive heat sink for nuclear power plants. Current cooling systems rely on evaporation for roughly 75% of the heat transfer from the cooling water to the atmosphere and on conduction and convection for the remaining 25% (23). Each pound of water which evaporates from a water-air surface transfers about 1000 BTU to the atmosphere.

The principal advantage of evaporative cooling is the elimination of thermal discharges to receiving waters. These systems generally recirculate the cooling water flow back to the condensers after heat has been dissipated from the water. Environmental benefits come at substantial additional costs, however. Large towers or ponds must be constructed and maintained. Moreover, such cooling systems result in losses of power plant efficiency. Since water coming to the condensers from cooling towers and ponds will be at higher temperatures than water from a surface water body in Northeast climates, steam must be condensed at higher temperatures. In effect, this means that more energy can be removed from the steam and used for power generation using once-through cooling than when cooling towers or ponds are employed. Various evaporative cooling systems are described briefly below.

The most common evaporative cooling system for large power plants in the U. S. is the natural draft tower (24). Although as of 1971 all such towers used fresh water, salt water towers are under study and are considered feasible (25). Natural draft towers are massive structures (Figure II-1),

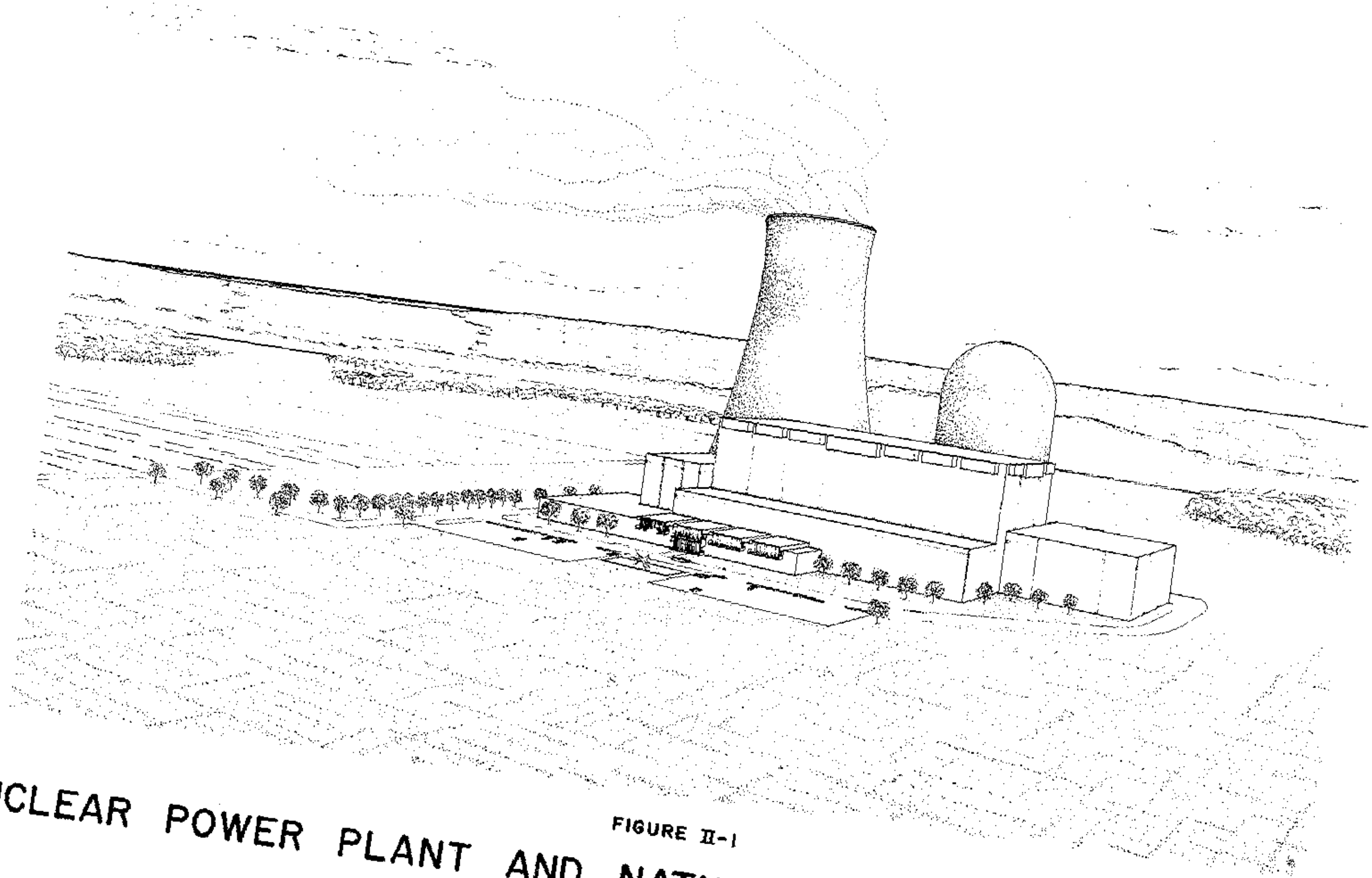

FIGURE II-1

NUCLEAR POWER PLANT AND NATURAL DRAFT COOLING TOWER with base diameters and heights of up to 500 feet. A 1100 MW nuclear plant could require two of these towers for waste heat dissipation. Make-up water is required to replace evaporative losses and to control the dissolved solids concentrations in the circulating water flow. In the case of freshwater towers, make-up requirements represent a direct consumptive use of water supplies.

Cooling towers are not completely free of environmental effects. The visual impact of these structures is substantial, and in areas of low topographic relief, towers may be objectionable for aesthetic reasons. Blow-down water, which has been drained from the circulating water flow when water is added to control dissolved solids, may be difficult to dispose of without environmental impact. Drift of entrained liquid water may result in ground deposition of salt particles within the immediate area of the tower. The increase in humidity or water vapor content of the air near a tower can produce fogging and ice formation at ground levels. Finally, the noise produced by natural draft towers is by no means negligible. With proper design, drift, fogging and noise are amenable to considerable control in natural draft cooling towers (22). Mechanical draft cooling towers, which were not considered in this study, result in substantially higher levels of drift, fogging and noise.

Cooling ponds are small artificial or natural lakes which require substantial land areas (1-2 acres per megawatt). Ideal design is a long narrow lake with cooling intake and outfalls at opposite ends so that pond circulation approximates "plug flow" conditions. Freshwater cooling ponds require minimal blow-down. Apart from possible destruction or alteration of natural areas during pond construction, the principal environmental impact is possible ground-level fogging. Pond costs vary widely, and are chiefly influenced by land values and soil permeabilities. The latter characteristic will determine whether or not artificial lining of the pond bottom is required.

Spray ponds or canals utilize sprays to enhance heat transfer to the atmosphere thus requiring only 1/10 to 1/20 of the surface area of a cooling pond (26). Depending on local wind conditions, drift and fogging may be comparable to natural draft towers. However, since water and water vapor is discharged closer to ground levels than with a tower effects in the immediate vicinity of the power plant may be more severe. Some noise is associated with spray ponds, but at lower levels than with towers.

Costs and Consumptive Water Use

Capital costs of alternative cooling systems are given in Table II-1. Additional cost information may be found in Woodson (25). Cooling system costs include pumps, piping and any condenser costs over and above those required in once-through cooling. Once-through cooling costs include the costs of outfall diffusers (5). Cooling pond costs are based on a 1500 acre pond, and include land aquisition costs appropriate to Suffolk County, L.I. ($5000 per acre in 1973), and the installation of an artificial pond lining. An attempt is

TABLE II-1

CAPITAL COSTS AND CONSUMPTIVE WATER USE OF ALTERNATIVE COOLING SYSTEMS

	Once Through	Natural Draft Tower		Spray Pond		Cooling Pond	
		Salt	Fresh	Salt	Fresh	Salt	Fresh
Power Plant Efficiency	32	31	31	31	31	31	31
Capital Costs ($\$10^6$)							
Cooling System	10.0	15.0	13.0	9.1	8.2	22.0[2]	21.0[2]
Additional Energy Production	1.0	5.5	5.5	5.0	5.0	4.4	4.4
Total	11.0	20.5	18.5	14.1	13.2	26.4	25.4
Fresh Water Make-Up (mgd)	-	-	18[1]	-	18[1]	-	12[3]

1 Assumes negligible blow-down water. If make-up is high in dissolved solids, make-up could be up to 100% larger.

2 Costs for Suffolk County, Long Island. Includes lining of pond bottom.

3 Based on Suffolk County Climate. Precipitation of 5 mgd, evaporation of 17 mgd.

made to estimate the cost of decreased plant efficiencies and power consumption associated with the various cooling mechanisms. This energy production capital cost indicates the cost of increasing the size of the nuclear power plant to maintain a 1100 MW net output. Thus, some energy consumption is required for pumping in a once-through system, and if net power output is to be maintained at 1100 MW, plant size must be increased to supply the cooling system power. It is not likely that plant sizes would actually be varied in this fashion, but for purposes of comparison, the energy production capital cost in Table II-1 is an indication of the additional real costs entailed in the use of cooling systems which diminish power plant efficiency and require substantial power for pumping. Details of cost derivations are given in the Appendix.

Fresh water make-up requirement or consumptive water use is indicated in Table II-1 for each system. In the case of freshwater towers and spray ponds, it is assumed that blow-down is negligible compared to evaporative losses. This would be the case if make-up water has a very low dissolved solids concentration such as ground water from Long Island's Magothy aquifer. For sources of less purity, blow-down could easily approach evaporative losses, resulting in a doubling of the make-up requirements for freshwater towers and ponds. Blow-down is typically small in cooling ponds, but evaporative losses are comparable to towers and spray ponds. The net make-up quantity is smaller for ponds in areas of high rainfall such as Long Island, since precipitation provides a substantial input (5 mgd for a 1500 acre pond). Capital costs for make-up water systems are not included in Table II-1, since they are highly dependent on plant location and available water sources. Typical costs of more than 15% of the cooling system cost have been suggested (25).

Environmental Impacts

The potential environmental impacts of alternative cooling systems are summarized in Table II-2. It should be noted that many of these impacts can be mitigated to an extent by appropriate system design. Also, only the most obvious impacts are included in the table. Since any large structure may have uncertain effects on an area's ecology, ecological impacts may occur which depend on the specific location of the power plant. The environmental impacts of evaporative cooling systems differ markedly from those of a once-through system. Comparison of Tables II-1 and II-2 indicated that avoidance of impacts on aquatic systems requires the substantial cost increases associated with evaporative cooling systems. Moreover, the evaporative cooling system with least impact, the cooling pond, is also the most expensive in areas with permeable soils and high land costs.

B. BENEFICIAL USES OF POWER PLANT WASTE HEAT

An alternative to the provision of elaborate structures for dissipation of waste heat is its utilization for productive purposes. The thermal enhancement of wastewater treatment is one example which is discussed in detail in the following chapter. A variety of

TABLE II-2

POTENTIAL ENVIRONMENTAL IMPACTS OF ALTERNATIVE COOLING SYSTEMS

System	Potential Environmental Impacts
Once-through	Entrainment, Impingement
	Thermal interference with aquatic life and food cycles
	Ecological changes due to local currents and mixing of biota and chemical constituents
Natural Draft Towers	Visual Impact
	Water Quality degradation from discharge of blow-down water
	Drift and salt deposition (more severe with salt water towers)
	Fogging
	Noise
Spray Ponds	Water quality degradation from discharge of blow-down water
	Drift and salt deposition
	Fogging
	Noise (less severe than towers)
Cooling Ponds	Disruption of natural area during construction
	Fogging (much less severe than towers or spray ponds)

additional applications are available, and in order to place the wastewater option in perspective, the various alternatives for beneficial uses of waste heat are reviewed in this section.

Since cooling water leaving a power plant's condensers may have a temperature on the order of 115^{o}F in July and only 80^{o}F in January, it is a low quality energy source for space heating and air conditioning of commercial and residential buildings or for industrial process use. With these major applications eliminated, waste heat utilization must follow one of two approaches. Either the quality of the heat must be upgraded or new and perhaps unconventional heat uses must be found.

A steam-generation power plant can produce high quality heat only by diverting a portion of the plant's high energy steam from electrical power production. During the steam-generation cycle, steam drives a succession of high, intermediate and low-pressure turbines. Steam which is extracted at any point prior to the low-pressure turbines will be of sufficient temperature and pressure to be a valuable heat source for many conventional applications (space heating, etc.)

A number of power utilities in the United State and Europe produce (and sell) electricity and heat in the form of steam from fossil-fueled plants (31). A broad application of this concept has been found in proposals that nuclear power plants be operated as "energy centers" for provision of all the electrical energy and heat requirements of new towns or industrial parks (32, 33). Energy centers offer potential for optimal utilization and conservation of energy resources. Conceptually, optimization can be achieved by consideration of (i), a community's total energy requirements and alternative energy sources, (ii), trade-offs between the value of steam as a heat source and an energy source for electrical power production at various points in the steam cycle, and (iii), an evaluation of beneficial uses and adverse impacts of heat rejected at power plant condensers.

A study from Oak Ridge National Laboratories has applied the energy center concept to a hypothetical new city of 400,000 (32). Steam for industrial use, hot water for space heating and air conditioning, heat for sewage treatment plants and warm water for greenhouse operations were the major non-electrical energy provisions of the energy center. A study for the Puerto Rico Water Resources Authority has proposed an energy-industrial center for which a nuclear plant would provide electricity and process steam for industrial use and desalination (33).

When nuclear power plants are operated to maximize electrical energy production (as opposed to both electricity and high-grade heat), various uses of low-grade waste heat are still possible. These uses can replace part or all of the usual heat dissipation mechanisms (discharge to surface waters, cooling ponds or towers, etc.). Low-grade heat utilization has not found wide application, but a number of studies and experimental programs have investigated feasibility and potential benefits. In addition to thermal enhancement of wastewater treatment, possible beneficial uses applicable to Northeast coastal areas include aquaculture, agricultures, recreation, and provision of warm water for municipal water supply use.

Aquaculture

The artificial addition of heat to an aquatic environment can have beneficial effects on a variety of animal species. Improved growth rates and the feasibility of introducing a commercially valuable warm water species into an area where natural waters are typically too cold for propagation are the more obvious benefits of using power plant waste heat in aquaculture.

Shrimp culture using warm waters has received more attention than any other salt-water aquacultural application. Shrimpt farming is a large industry in Japan, and heated cooling waters have been used to accelerate growth (31, 34). Experimental studies of shrimp production using power plant cooling waters have been undertaken in Great Britain and the United States (31). Japanese shrimp farms are operated at temperatures between 60^{o} and 90^{o}F and the shrimp are grown in bins 500 square feet in area. With nine tons of water passing through each bin per hour, the area required to dissipate one-half of the waste heat from a 1100 MW nuclear power plant would be in the order of 1500-2000 acres. Shrimp can be grown in either an enclosed and protected area of a coastal bay or in salt water ponds. Lobsters and oysters are other marine organisms which can potentially be "farmed" in thermally-enriched environments. Studies have shown that the normal seven-year time of maturity for lobsters can be reduced to two years in warm water (31). Oysters are being successfully grown using warm water from the Long Island Lighting Company's Northport and Barrett Power Stations (35).

Carp and catfish are the principal fresh water organisms which have been investigated for commercial production using waste heat. Chopped carp is useful as a high protein feed ingredient, and has potential for replacement of fish meal in certain livestock feeds. At 1969 market prices, commercial production of chopped carp is an existing cooling pond could yield a net return of 4% on investment in the Pacific Northwest area (36). Catfish are in substantial demand in parts of the U.S., particularly the Southwest, and catfish farming is an established industry. Again, for the Pacific Northwest, a potential investment yield of 17% is possible when catfish are cultivated in an existing power plant cooling pond (36).

The viability of aquacultural use of waste heat in the Northeast is conjectural. Technical feasibility would not a-pear to be a problem. Power production would not be affected, but if cooling ponds were used for aquaculture, care must be taken in the design of cooling water intakes to prevent entrainment. Also, larger ponds may be required to prevent potentially lethal high summer temperatures. If marine aquaculture is practiced along shorelines, thermal discharges may have adverse effects on other marine life.

The economics of thermally-enhanced aquaculture are dependent on market conditions. The Northewast has no substantial marked for chopped carp or catfish at present, but demand for shrimp, oysters and lobster is high, indicating a relative advantage for mariculture (salt-water aquaculture). A number of problems are associated with mariculture, however. If shoreline farming is used, the warmed waters and animal waste products will have uncertain effects on the surrounding coastal ecology. Ponds would require large land areas if significant amounts of waste heat are to be utilized. It appears that culture in a salt water cooling pond may be the most feasible procedure.

Agriculture

Agricultural uses of waste heat include frost protection and control of crop humidity and temperature conditions by warm water irrigation, soil warming and greenhouse heating and air conditioning.

Irrigation with warm water has been extensively investigated in an Oregon project sponsored by the U.S. Environmental Protection Agency and the Eugene, Oregon, Water and Electric Board (37, 38). Irrigation experiments were designed to investigate the use of thermal effluents for orchard frost protection, for control of temperature and humidity in the near ground atmosphere surrounding the growing plant and as a substitute for the normal (cool) water crop irrigation requirements.

In comparison with the use of water at ambient temperatures, study results indicated that warm water may offer somewhat better frost protection and atmospheric control, and has no adverse effects on plants when used for irrigation. However, the warming of soil by underground pipes carrying warm cooling water was suggested as "the most beneficial use of thermal water in agriculture." (38).

As suggested in the above study, soil warming by pipes carrying heated water can produce substantial agricultural benefits. Heated soils may result in yield increases of 14 to 85% for a variety of grain, vegetable and fruit crops (7). Soil warming can function as a close-cycle (recirculating) cooling system for a nuclear power plant. As cooling water circulates through the underground pipe network, heat is dissipated to the soil by conduction and cooled water is returned to the condensers. Compared to other cooling mechanisms, there are no obvious adverse environmental impacts. The principal technical problem associated with soil warming is drying of the soil, thus requiring irrigation in excess of a crop's normal requirements.

Cropping areas required for heat dissipation vary with pipe depth, spacing and radius and soil thermal conductivity, and for a 1100 MW nuclear plant areas of 12000-30000 acres would be necessary (39). Economics of the scheme can be expected to be highly variable, depending on the above factors as well as land availability and crop type. In areas with significant quantities of contiguous agricultural lands and available irrigation water, soil warming appears to be worthy of further study as an alternative for dissipation and utilization of at least a portion of power plant waste heat.

The heating and air conditioning of greenhouses using power plant cooling water has received considerable attention (7,39,40,41). Studies have included both conceptual designs (40) and small field-scale operations (41). A particular advantage of this waste heat use is its year-round operation, utilizing cooling water for heat in winter and for temperature and humidity control in summer. An estimated 400-500 acres of greenhouses would be required for heat dissipation from a 1100 MW nuclear power plant. Incremental greenhouse investment costs have been estimated at $35,000 per acre to utilize power plant cooling water for heating and cooling. This cost includes all additional equipment needed for delivery and use of waste heat for greenhouses located at the power plant site. The costs of an emergency heating system for use during power plant shut-downs is also included. Although the greenhouse investment costs may thus increase by 25%, normal annual heating costs of $3,000-$10,000 per acre will be saved by use of the power plant waste heat (40).

A 500-acre greenhouse facility (Figure II-2) would be much larger than any existing U.S. operation, although European installations of up to 250 acres have been made. Marketing of greenhouse produce may be a problem, since 500 acres could supply most of the fresh vegetable needs of a city of 2.5 million (40). A second problem area is the potential for plant diseases at the high humidity levels produced by the evaporative pads used for heat dissipation and air conditioning in the greenhouse (41).

Recreation

The lakes and coastal areas of the Northeast have relatively short recreation seasons since water temperatures are too cold for swimming during much of the year. By diverting cooling water discharges to swimming areas, the warm effluent could extend bathing seasons, promoting the additional utilization of what are presently seasonally-used recreation and tourist facilities. Conceptual studies have indicated that substantial warm water swimming areas can be maintained in lakes and coastal areas (31). The application of this beneficial use has severe limitations, however. The adverse environmental effects of surface water thermal discharges would not be mitigated and adverse climatological conditions (low air temperatures and precipitation) may still limit swimming opportunities.

Water Supply

A municipal water supply system can be coupled with power plant cooling either by diverting water to plant condensers before it enters the water distribution system or, if high quality cooling water is being used (such as that supplied from ground waters), it may be introduced into water supply mains after passing through the condensers. In either case, warm water is delivered to consumers in place of the cool water which is normally received. Such a scheme would result in multiple water use and reduce household energy requirements for water heating.

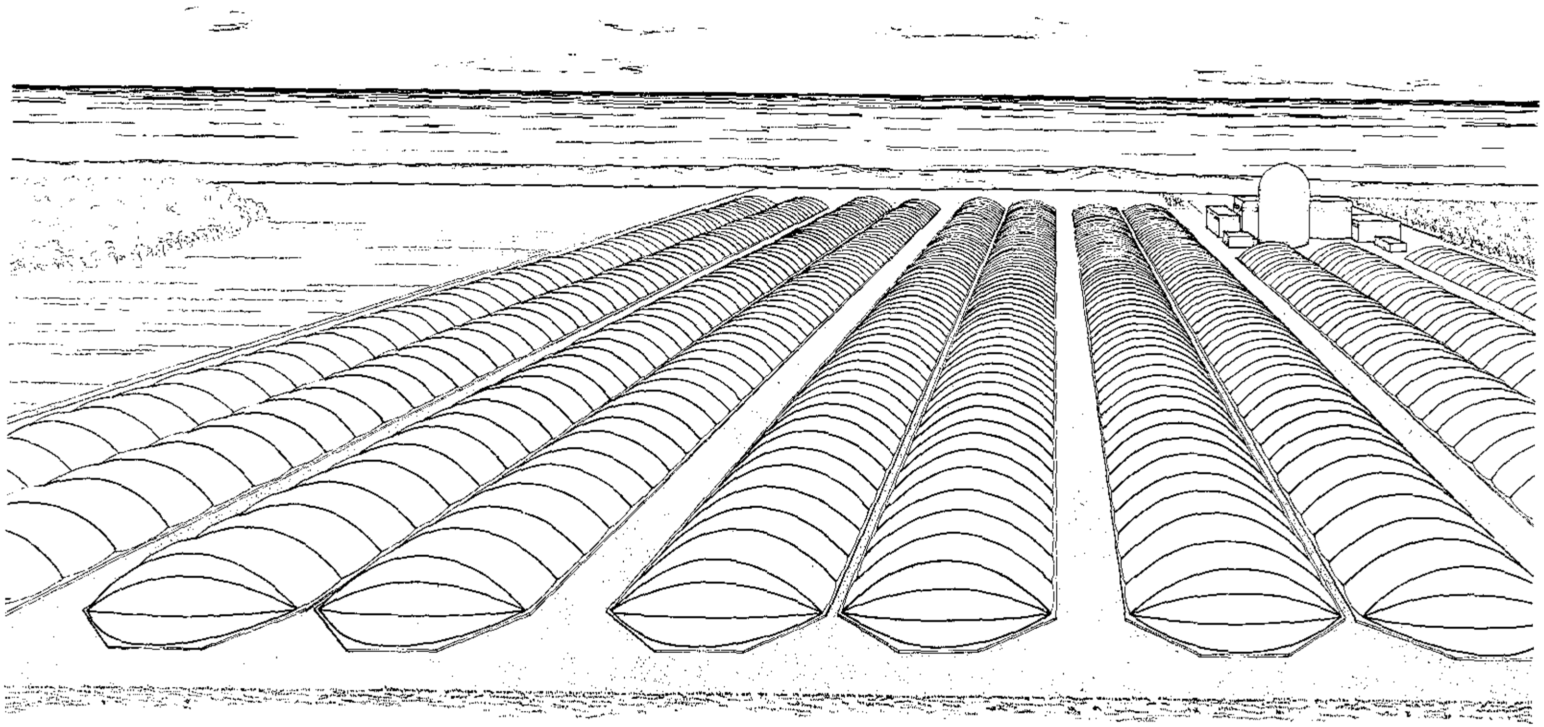

FIGURE II-2

BENEFICIAL USE OF POWER PLANT WASTE HEAT FOR GREENHOUSE ENVIRONMENTAL CONTROL

An evaluation of conjunctive water supply and power plant cooling use of water has been made for the Seattle area (42). With Seattle's 140 mgd water supply heated to 100°F, households would receive water at maximum temperatures ranging from 91°F to 100°F. These temperatures would require modifications of consumers' water meters which are designed for cooler water at a cost of $10 million. Since the total water flow would be less than 20% of an 1100 MW nuclear power plant's cooling water, the meter cost alone makes the alternative uncompetitive with even the most expensive evaporative cooling methods. However, since approximately 60% of Seattle's residential electricity use is used for heating water, a total energy saving of 25 to 50% for water heating may be realized when households receive water at 90°F. This represents a maximum dollar savings of $12 million per year, and, of course, a reduction in total electrical demand for the area.

The use of water for both cooling and domestic supply is most feasible with a power plant located near a large centralized water system, and in most cases municipal supply could provide only a fraction of the power plant's cooling needs. The costs of meter modification and additional storage and piping requirements result in prohibitive investment costs with existing systems. The alternative may be attractive with water supply systems which are either unmetered or have meters suitable for warm water. As the cost of residential electricity rises, the attendant reduction in electricity use for domestic hot water heating would greatly increase the cost savings associated with the alternative.

Operational problems associated with the scheme include phasing of water supply and cooling water flows, additional corrosion of pipes and appliances due to warmer water and possible disinfection difficulties at higher temperatures.

Summary

In general, the beneficial uses of waste heat outlined above are at the conceptual or experimental level and have yet to see application. Economic viability is uncertain, since commercial experience is lacking and even in the best of cases, it is unlikely that a single beneficial use could utilize more than a fraction of the waste heat from a nuclear power plant. Yet certain of the alternatives, such as greenhouse heating and air conditioning and mariculture may be attractive in the Northeast. Potential product markets exist and there appears to be no severe technical problems which would limit implementation. Moreover, as the cost of energy and food both increase, the use of waste heat for food production may result in significant social benefits.

CHAPTER III - THERMAL ENHANCEMENT OF WASTEWATER TREATMENT

Many of the treatment processes which are used to stabilize and renovate wastewaters are temperature-dependent. Within certain limits, the efficiencies of these processes are likely to improve as the wastewater temperature is increased. A sewage treatment plant which is treating wastewater at a temperature of 90°F can be expected to be smaller and less expensive than a plant which achieves a comparable level of treatment for wastewater at 65°F.

The prediction of increased treatment efficiency with elevated temperature is based on an understanding of the basic physical, chemical and biological processes which are used in wastewater treatment. It is known that solids settle more rapidly, chemical reactions proceed at faster rates and bacterial oxidation is enhanced by temperature increases. The limits of such improvements in efficiency are not known with precision, since extensive field experience with warmed wastewaters is lacking. The sewage that is received by municipal treatment plants may typically be at 65°F, and there is seldom an economical heat source which could be used to elevate this temperature.

The waste heat from a nuclear power plant is a potential heat source for thermal enhancement of wastewater. Although a large conventional treatment plant might be capable of utilizing only a fraction of the waste heat normally rejected to the environment by a nuclear power plant, such heat should be sufficient to significantly enhance treatment efficiency. Moreover, a potential exists for complete integration of power plant cooling systems and wastewater treatment in such a fashion that treatment and cooling can be combined in a compatible system.

A. TEMPERATURE EFFECTS ON WASTEWATER TREATMENT

Existing information on the benefits of thermal enhancement of wastewater treatment processes has been recently summarized (5,6,43). Standard design formulae for treatment processes generally contain temperature-dependent parameters. With the exception of activated carbon adsorption processes, these formulae predict improved efficiencies for all conventional and advanced wastewater treatment processes when temperatures are raised above normal (ambient) conditions (5,6). These improvements could result in decreases in the sizes of the various components of a treatment plant with attendant reductions in construction and operating costs. Estimated size reductions in process units found in a typical activated sludge treatment plant are summarized in Table III-I.

Since field experience with heated wastewater treatment processes is lacking, results such as those shown in Table III-1 must be interpreted with care. The applicability of standard design procedures to processes operated at elevated temperatures has not been conclusively established, and some evidence indicates that such methods may not accurately predict the performance of biological treatment systems (43).

Conceptually, heat could be added to a treatment plant at any number of points. The plant influent could be sufficiently warmed to maintain elevated temperatures throughout the process flow, or alternatively, heat could be added at several points in the plant to attempt to maintain optimal operating temperatures in each process unit. In the absence of field experience with thermal enhancement, the most straightforward procedure would be the direct addition of heat to influent sewage.

TABLE III-1

PREDICTED REDUCTIONS IN TREATMENT PROCESS UNITS DUE TO A 10° C (18°F) INCREASE IN TEMPERATURE (20°C TO 30°C: 68°F TO 86°F)

Process Unit	% Reduction in Unit Size[1]
Grit Chamber	17
Primary Clarifier	20
Aeration Basin	10
Final Clarifier	20
Chlorine Contact Tank	28
Thickener	21
Anaerobic Digestor	39
Vacuum Filter	14
Centrifuge	20

[1] Ref. 5, Appendix A

B. HEAT TRANSFER METHODS

There are two sources of heat in a nuclear or fossil-fueled power plant which could be used for warming wastewater. The first of these is the steam which is used to drive the turbogenerators. As steam passes through successive high, intermediate and low-pressure turbines, the subsequent expansion greatly decreases its temperature and pressure. Steam could be removed at any point in the process, and such removal would have varying effects on power plant operation. If steam is extracted at any point prior to the last low-pressure turbine, some loss in power generating capacity would result. Moreover, since steam is subsequently condensed and regenerated in boilers, any removal would require the addition of make-up water to the steam/water cycle. Boiler water must be relatively free of impurities, and its replacement is costly.

The removal of spent steam (steam which has passed through the last low-pressure turbine) would require more boiler make-up than removal of steam after the intermediate turbines, since greater quantities must be withdrawn to heat the wastewater. There may be a critical point at which to remove steam from the power generating cycle such that the cost of make-up water and steam transfer to wastewater treatment balance the costs associated with lost generating capacity.

The other source of heat which could be available to wastewater is associated with the heat which is given up in condensation of the process steam. This heat is removed from the condensers by large amounts of cooling water (850 million gallons per day in the case of the nuclear plant). This is truly a waste heat source and transfer to wastewater could be either by means of heat exchange with the cooling water or, more directly, by passing wastewater through the plant condensers, in effect utilizing wastewater to satisfy part of condenser cooling requirements. The use of condensation heat, as above, would not require any modification of the basic steam-power generating cycle of the power plant.

Several heat transfer alternatives are given detailed consideration. The first of these is a barometric condenser, which would inject spent steam into wastewater before it enters the secondary treatment plant. The second alternative is the use of degritted wastewater as cooling water for part of the power plant process steam by means of a separate or sectionalized condenser. The wastewater treatment plant utilized in both alternatives will be a conventional activated sludge treatment plant as indicated in Figure III-1. Wastewater will be considered to have an average ambient temperature of 65°F. Sufficient heat will be added to the influent to insure a temperature of 86°F in the activated sludge units, this being approximately the optimal temperature for the mesophilic bacteria which oxidize waste organic material (5). A third alternative will be a complete integration of the power plant cooling and wastewater treatment systems by means of a combined cooling and waste stabilization pond.

The 1100 megawatt nuclear power plant described in Chapter II will provide the heat source for each alternative. A terminal steam temperature of 120°F is assumed. Details of technical and cost analyses are given in the Appendix.

Barometric Condenser

A barometric condenser is a most efficient means of heat transfer from steam to water (44). Steam is condensed directly on the water surface, giving up its entire latent heat of evaporation to the water. Spent steam from a power plant can be used to heat the wastewater flow, and thus the influent to the treatment plant will consist of both the wastewater and condensed steam. The removal of some spent steam could permit reduction of the power plant cooling system, since less steam is condensed for return to boilers. As indicated earlier, boiler water make-up will be necessary to replace the extracted steam.

Steam quantities which are required to heat various wastewater flows to 93°F (which ensures an activated sludge unit temperature of 86°) are given in Table III-2. The percent of waste heat from the 1100 megawatt nuclear power plant utilized in wastewater heating and boiler

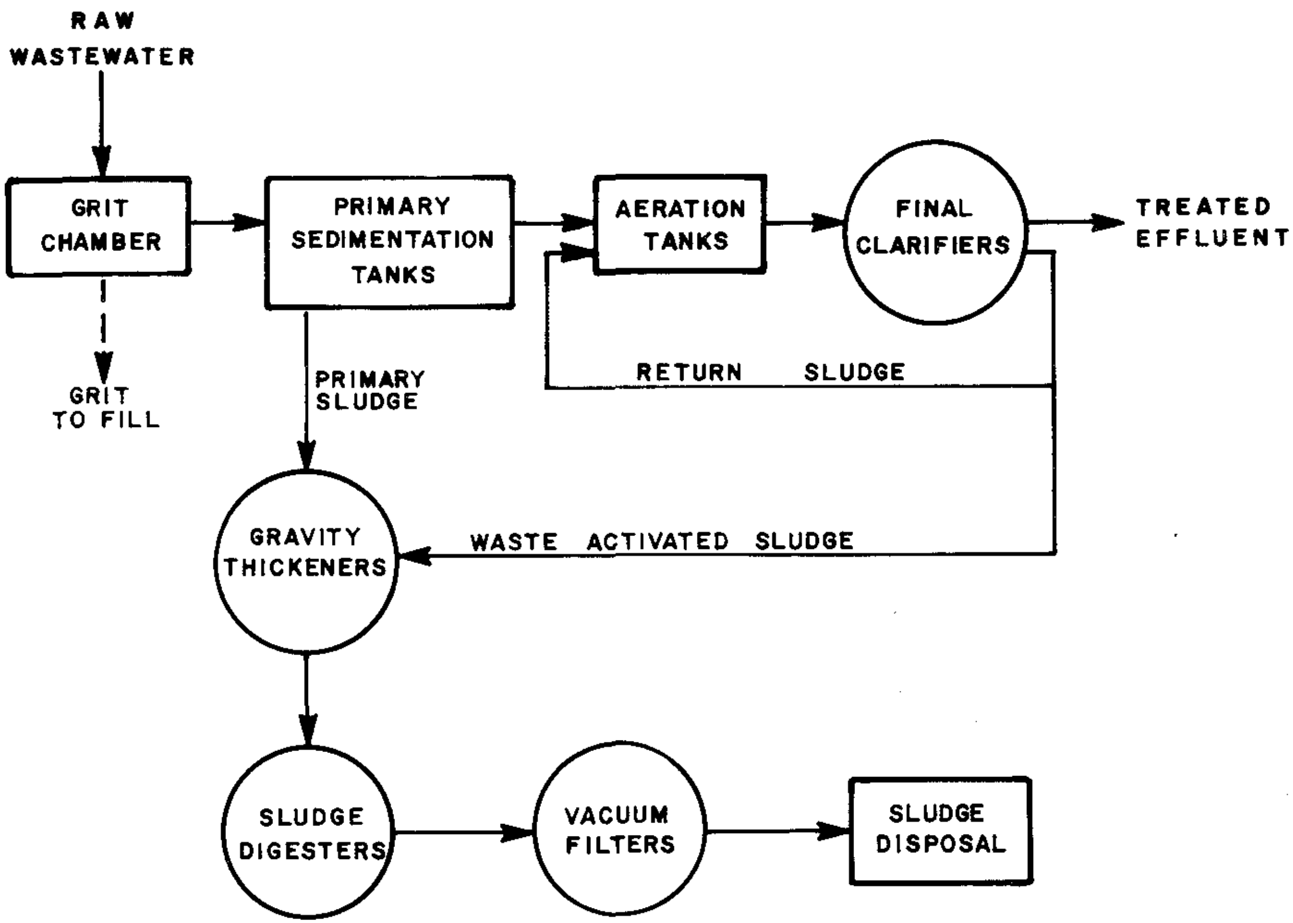

FIGURE III-1

SECONDARY WASTEWATER TREATMENT PLANT — PROCESS FLOW make-up requirements are also given in the table.

TABLE III-2

BAROMETRIC CONDENSER CHARACTERISTICS

	Wastewater Flow (mgd, million gallons per day)				
	10	20	30	40	50
Required Steam flow (10^6 lb/hr)	0.12	0.25	0.36	0.49	0.61
% of Waste Heat Utilized	1	3	4	5	7
Boiler Make-up (mgd)	0.32	0.72	1.04	1.41	1.75

The quantities listed in Table III-2 are sensitive to ambient wastewater temperatures. An average annual temperature of 65°F was assumed, but seasonal variations are likely. With a wastewater temperature of 50°F, the steam flow required to heat 50 mgd of wastewater to 93°F is 0.94 10^6 lb/hr, which would utilize 10% of the power plant's waste heat. A wastewater temperature of 75°F would require only 0.38 10^6 lb/hr, or 4% of the waste heat.

The capital cost of a barometric condenser for a 50 mgd waste flow is estimated to be $200,000 (5). The cost of a 50 mgd wastewater treatment system for heated wastewater is shown in Table III-4.

The use of a barometric condenser to heat wastewater with spent steam from a nuclear power plant appears to be technically feasible. Economic feasibility will depend on the cost of supplying boiler water make-up. Problems associated with the alternative involve radiation safety, maintenance, and variability of wastewater flows and heat loading.

Although the steam passing through the turbines in a pressurized water reactor nuclear plant is theoretically free of radiation, the possibility of radiation leaks to the steam and subsequent contamination of the wastewater cannot be ignored, and there is a definite probability that the Atomic Energy Commission licensing procedures would not approve of the steam being removed for wastewater heating. Maintenance difficulties with the barometric condenser would be associated with the prevention of anaerobic conditions which could produce bacterial growth and odors. The variability of wastewater flows could result in less heat utilization for flows below the design or average flow, and a reduced treatment level at higher flows. In the event of a power plant shutdown, no heat would be transferred to the wastewater and a treatment plant designed for heated wastewater could not adequately treat unheated sewage.

In summary, the barometric condenser is technically feasible and may be economically advantageous. It would, however, utilize relatively small amounts of waste heat, and since wastewater flows are variable, no significant reduction in the power plant cooling system can be envisioned. Moreover, concern for radiation safety and the possibility of intermittent lowering of treatment effluent quality due to power plant shutdown may effectively preclude approval of the alternative by regulatory agencies.

Sectionalized Condenser

Degritted wastewater can be utilized as cooling water for the condensation of exhaust steam in a nuclear power plant. Since the cooling water requirements of such plants is in the neighborhood of 850 mgd, wastewater volumes will seldom be sufficient to satisfy complete cooling needs. Moreover, mixing of the normal cooling water with sewage would create large amounts of contaminated water which could interfere with the operation of closed cycle cooling systems or would necessitate the treatment of the entire cooling flow in open cycle (once-through) systems. A separate or sectionalized condenser for wastewater flows is an obvious solution to these difficulties. Part of the power plant steam would then be condensed using wastewater and the remainder with a conventional cooling flow.

The design of a condenser utilizing degritted wastewater is a direct function of the heat transfer coefficient of the wastewater. This coefficient depends on several factors, one of which is the fouling resistance of the cooling water. Since experience with wastewater use in condensers is minimal, fouling resistance can be estimated only from reported values for natural waters which are polluted (5,45). Based on these values, heat transfer coefficients of 130 to 310 BTU/hr-ft^2-°F may be expected. Condenser costs are proportional to condenser areas which vary inversely with heat transfer coefficients, and since typical coefficients for salt water coolant are 400-450 BTU/hr-ft^2-°F, costs may be substantially increased with wastewater coolant.

Condenser areas required and waste heat utilized by a sectionalized condenser are listed in Table III-3. As with the barometric condenser, wastewater is heated from 65°F to 93°F. An average heat transfer coefficient of 185 BTU/hr-ft^2-°F as suggested in an earlier study (5) is used to determine surface areas. The capital cost of a condenser for a 50 mgd wastewater flow is estimated to be $840,000. Comparison of condenser costs utilizing sea water and wastewater indicates an additional installed cost of $540,000 - 580,000 when wastewater is used (5).

TABLE III-3

SECTIONALIZED CONDENSER CHARACTERISTICS

	Wastewater Flow (mgd)				
	10	20	30	40	50
Condenser Area (ft^2)	13,500	27,000	41,000	55,000	68,000
% of Waste Heat Utilized	1	3	4	5	7

A sectionalized condenser is a technically feasible alternative for wastewater heating. Principal technical uncertainties are condenser fouling and possible corrosion associated with the wastewaters. Stainless steel or copper nickle alloys used for condenser construction with saline cooling water may resist corrosion, but this is somewhat uncertain (5). Fouling resistance will have a major impact on financial feasibility, since lower resistance values may reduce surface areas to levels comparable to salt water cooling. Maintenance problems associated with condenser fouling may occur, but their severity is again unknown. There are no radiation safety problems associated with the alternative, but the difficulties arising from wastewater flow variation and power plant shutdown which were associated with a barometric condenser also characterize the sectionalized condenser. Again, the modest quantities of waste heat utilized and the problem of flow variability preclude more than marginal cost savings in a nuclear power plant cooling system.

The costs of a conventional 50 mgd activated sludge treatment plant have been compared with the same type of plant with influent heated through use of barometric or sectionalized condensers (Table III-4). Thermal enhancement results in capital cost savings of 9% and annual cost savings of 5%. Balanced against these cost savings are the condenser cost and, for the barometric condenser, the costs associated with boiler water make-up. Unless substantial savings could be realized from reductions in power plant cooling systems (which, as noted above, is unlikely) or from the conjunctive use of a site and administration buildings by the power and treatment plants, the above alternatives for thermal enhancement of wastewater treatment do not appear to be economically attractive.

TABLE III-4

COST COMPARISONS FOR A 50 MGD ACTIVATED SLUDGE WASTEWATER TREATMENT PLANT - UNHEATED AND HEATED BY BAROMETRIC AND SECTIONALIZED CONDENSERS (CONDENSER COSTS NOT INCLUDED)

	Unheated	Heated	
		Barometric Condenser	Sectionalized Condenser
Capital Cost ($\$10^6$)	16.1	14.7	14.7
Annual Cost ($\$10^6$)	2.03	1.93	1.92

The environmental impacts of the alternatives will depend on the methods of wastewater disposal, which are discussed in the next chapter. Effluent quality will be equivalent to an unheated secondary treatment plant. The average annual temperature of the effluent is estimated to be 85°F (5).

A final point should be made relative to these two alternatives. The implementation of an integrated power-wastewater management system could be a difficult task. If waste heat is to be dissipated by wastewater, and if the wastewater treatment plant is designed on the basis of elevated temperatures, both the power plant and the treatment facility must begin operation on approximately the same date. Given the differences in construction technology for the two systems and the delays inherent in licensing of construction and operation of nuclear plants, such coordination seems unlikely.

Cooling/Stabilization Pond

A third alternative for the transfer of power plant waste heat to wastewater is the construction of a large pond or lake which would serve as both a cooling and waste treatment system. Wastewater and precipitation would be the only water inputs into the pond, and cooling water would circulate through the pond. Two sets of inlets and outlets would be provided, one for wastewater influent and effluent (overflow) and the other for the circulating cooling water.

In regions with high land costs, temperate climates and permeable soils, ponds would not normally be considered economically attractive alternatives for disposal of large amounts of heat or wastewater. However, a large pond serving both purposes has potential advantages. The elevated temperatures in a cooling pond may enhance waste stabilization and wastewater flows would satisfy make-up water requirements of the cooling pond. In the event that ultimate disposal of wastewater is by land application, winter storage may be necessary, and a cooling/stabilization pond may also serve this purpose.

The complete integration of power plant cooling, wastewater treatment and perhaps wastewater storage has a potential for substantial economic, environmental and regional benefits. The technological and performance uncertainties are also large, however, and the alternative's advantages are conditional on the demonstration of technical feasibility.

The cooling/stabilization pond considered in this study has a surface area of 1500 acres and a maximum average depth of 10 feet. Two modes of operation are possible. If winter storage of wastewater is required, as with a land disposal system, the pond depth will vary during the year. If year-round wastewater discharge is possible, a constant depth of 10 feet can be maintained.

The temperature characteristics of a 1500-acre pond located on Long Island are given in Table III-5. Temperatures will depend on pond design, and variations of several degrees from indicated values are possible. Evaporation and precipitation would average 17 and 5 mgd, respectively, for a net natural water loss of 12 mgd. The pond bottom would require sealing on Long Island to prevent additions or losses due to seepage.

Wastewater treatment in a facultative stabilization pond is achieved in aerobic surface and anaerobic subsurface regions. The pond approximates a highly eutrophic lake, with algal photosynthesis providing a major share of oxygen needed for oxidation of organic material. Suspended matter settles in the pond and is decomposed anaerobically. Removal of organics is considered to be a function of pond detention time and a reaction rate which is temperature-dependent (46,47).

Use of conventional design formulae with reaction rates determined by the average pond temperatures given in Table III-5 would indicate a BOD removal of at least 95% for even raw sewage influents of up to 100 mgd. However, summer temperatures in the pond would be somewhat above the level considered optimal for aerobic oxidation, and these temperatures may also inhibit algal growth. Moreover, unless algal cells are removed from the pond effluent a substantial and highly variable oxygen demand may be exerted during algal decomposition. Typical BOD loading rates for unheated stabilization ponds which achieve 80 to 90% BOD removal are 20-50 lb/day per acre in areas with winter ice cover and 50-150 lb/day per acre in areas with mild winters (46). Such loadings may not be appropriate for heated ponds. Since design and field experience is limited to unheated stabilization, the quantities of organics present in a cooling/stabilization pond effluent must be considered unknown.

TABLE III-5

TEMPERATURE CHARACTERISTICS OF A 1500 ACRE COOLING POND FOR A 1100 MW NUCLEAR POWER PLANT

	January	July
Cooling Water Discharge Temperature (°F)	80	115
Cooling Water Intake Temperature (°F)	55	90
Average Pond Temperature (°F)	68	102

The concentrations and forms of phosphorus and nitrogen in the effluent are equally uncertain, since wide variations have been observed in existing (unheated) ponds (6). Suspended solids in the pond waters should consist almost entirely of algal cells and concentrations are likely to be highly variable. However, the nutrient content of wastewater should limit suspended solids concentrations to a maximum of 4000 mg/l (47). Observed concentrations in unheated ponds range from 200 to 4000 mg/l (48). Dissolved solids can be readily predicted and will depend on wastewater flows. Sludge build-up on the pond bottom can be estimated based on wastewater BOD and suspended solids concentrations.

The treatment characteristics which can be reasonably estimated are given in Table III-6. Except for detention times, all indicated values will be equivalent for a pond maintained at a ten foot depth and one which experiences a seasonal variation in depth.

Possible problems associated with the cooling/stabilization pond are related to the uncertainties in pond performance and can be classified as power plant cooling, wastewater stabilization and general system problems. If the quality of pond effluent is comparable to that achieved in secondary treatment, there is little direct evidence that would indicate power plant condenser difficulties. Maximum allowable values of dissolved and suspended solids of 1000 and 5000 mg/l would not be exceeded for wastewater influents greater than 20 mgd. There is a greater possibility of condenser fouling by algae and possible lower heat transfer coefficients than normally encountered in closed-cycle pond cooling systems. If the pond is used for winter storage of wastewater, its cooling performance may differ from that indicated in Table III-5. For storage of 30 mgd of wastewater during November, December, January, February and March, pond depth would vary from 3 ft. in October to 10 ft. in April. At the 3 ft. depth the cooling flow of 850 mgd would comprise more than 50% of the total pond volume.

Variations in depth and flow regime could also have unpredictable effects on algal growth, waste stabilization and sludge deposits. It is conceivable that the pond could be covered with algae in the winter, but that high temperatures in summer could limit algal growth and result in a totally anaerobic pond. The relative desirability of using raw, primary, or secondary effluent as pond influent can be assessed from examination of Table III-6. Since the pond is essentially a secondary treatment system, there would seem to be little advantage to secondary treatment of wastewaters before they enter the pond. Moreover, the nutrient concentrations in such wastewaters would still be sufficient to produce highly eutrophic conditions. Raw sewage could exceed recommended BOD loadings for unheated ponds, and may produce a rapid build-up of sludge deposits (approximately one foot in seven years at 30 mgd). Given the uncertainties of pond performance it would appear advisable to require at least primary treatment of wastewater prior to discharge into the pond.

The presence of a 1500 acre eutrophic lake may create problems of social acceptance. Public concern for water quality may result in an unfavorable reaction to the deliberate construction of a eutrophic lake.

TABLE III-6

WASTE TREATMENT CHARACTERISTICS OF 1500-ACRE COOLING/STABILIZATION POND

	Wastewater Inflow (mgd)				
	20	30	40	50	100
Detention time (days)	610	270	180	130	60
Effluent Dissolved Solids (mg/l)	500	340	280	260	220
BOD Loading (lb/day-acre)					
Raw Influent	22	33	45	56	111
Primary Influent	13	20	27	33	67
Secondary Influent	3	4	6	7	14
Sludge Build-Up (ft/yr)					
Raw Influent	0.10	0.14	0.19	0.24	0.48
Primary Influent	0.05	0.08	0.11	0.13	0.27
Secondary Influent	0.02	0.02	0.03	0.04	0.08

The investment cost of a 1500 acre cooling/stabilization pond and a 30 mgd primary wastewater treatment plant is estimated to be $30,200,000. Pond costs include land aquisition for the Suffolk County area of Long Island and the installation of an artificial pond lining. By comparison, the combination of a natural draft evaporative cooling tower and secondary wastewater treatment would provide comparable performance with an investment of $28,300,000. The latter alternative cannot be assumed to be economically preferable to the cooling/stabilization pond, however. The cost of a make-up water system is not included in the cooling tower costs, and pond costs include high land values and artificial lining. The latter has been estimated at $5,800,000 for the 1500-acre pond, and this lining would not be necessary in an area with impermeable soils. In the advent that wastewater disposal is by land application, a cooling/stabilization pond is definitely less expensive than the cooling tower-secondary treatment plant alternative. Winter storage of a 30 mgd wastewater flow requires a volume equal to a 7 foot deep, 1500-acre pond. A cooling/stabilization pond would provide this storage at no additional cost, but other alternatives for treatment and cooling would require the construction of an additional storage facility.

Other significant benefits could be realized by the cooling/stabilization pond. The coordination of power plant and waste treatment construction and operation would not be as critical as it is for the barometric and sectionalized condenser alternatives. The pond and primary treatment facility could be constructed and operated before power plant operation began. Moreover, wastewater flow variations and power plant shutdowns would not cause significant operating problems.

If the cooling/stabilization pond is surrounded by large acreages of agricultural land which are irrigated, areas of open land would be preserved. Low population densities in such an area should also simplify nuclear power plant siting problems.

Summary

Three alternatives for the integration of wastewater treatment with power plant cooling have been reviewed. Two of these alternatives, heat transfer with a barometric or sectionalized condenser, could result in estimated 5% reductions in the annual costs of a 50 mgd, activated-sludge wastewater treatment plant. Each would require additional power plant cooling expenses for condensers and, with a barometric condenser, for boiler water make-up. Performance uncertainties related to variable wastewater flows, power plant shutdowns, and possible condenser fouling characterize both alternatives. Potential radiation hazards may effectively limit the barometric condenser from further consideration. The viability of a sectionalized condenser for heating wastewater depends on demonstrating that greater efficiencies in wastewater treatment are possible with thermal enhancement than would be predicted by standard design procedures.

A cooling/stabilization pond would require an investment comparable to alternative cooling and treatment systems in areas with high land costs and permeable soils. In other areas, the pond would cost substantially less. With land disposal of wastewater, the cooling/stabilization pond would provide winter wastewater storage, while other cooling and treatment alternatives would require additional facilities. The attractiveness of a cooling/stabilization pond lies in the provision of a single structure for the multiple purposes of power plant cooling, wastewater treatment and wastewater storage. Cooling and waste stabilization performance cannot be predicted with certainty, however, and realization of potential benefits is dependent on a demonstration of technical feasibility.

CHAPTER IV - WASTEWATER DISPOSAL

The alternatives for disposal of treated municipal wastewaters are discharge to surface waters, ground water recharge, land application and direct reuse. The selection of an appropriate disposal method is seldom obvious, since each of the above has an associated set of economic, environmental and water supply impacts which will vary with locality, wastewater characteristics and operating procedures.

In coastal areas, surface discharge of wastewater is typically accomplished by outfalls to bays or estuaries. The environmental impact of such effluents is a function of wastewater volumes and degree of treatment. In the case of heated wastewaters, discharge results in a thermal pollution loading on receiving waters in addition to normal organic and chemical pollution. Since the receiving water is saline, no further water supply use of the wastewater is possible unless desalination is employed.

Ground water recharge with municipal wastewater can be effected through recharge basins or injection wells. The motivation for this disposal alternative is augmentation of ground water reservoirs for control of salt water intrusion or provision for future water supply use. The performance of recharge facilities is dependent on soil and aquifer properties and a very high level of wastewater treatment is usually necessary to prevent well or soil clogging and contamination of ground water supplies with pathogens and nitrates (18,50). Nitrate pollution is of particular concern, since nitrates, which will persist in the ground water long after introduction, can cause methemoglobinemia, a potentially fatal disease of small infants. Nitrates may also have toxic effects on livestock and other domestic animals. A maximum nitrate concentration of 10 mg/l (as nitrogen) is recommended by the U.S. Public Health Service for drinking water.

The application of treated wastewater to soil covered by plants has received much attention in recent studies. The alternative has seen wide application in various parts of the world for many years and a number of small U.S. cities and food processing industries dispose of wastewater by this means (51,52,53). Although land application has not been used in urban or developed areas of the Northeast, it has been included as a disposal alternative in regional wastewater management plans (54).

Plant cover for disposal areas has included grass, forest, agricultural crops and natural vegetation. After renovation by a combination of biological, chemical and filtration processes within the plant/soil system, the wastewater may enter surface waters or recharge ground waters.

The direct reuse of wastewater is in many ways the most attractive of disposal methods, since wastewater thus becomes a water supply source and the environmental impacts of other disposal methods are avoided. Although wastewater is often recycled indirectly as municipal water supply (as for example, when an upstream city discharges sewage into a river used by a downstream community for water supply), direct reuse for domestic purposes is rare in the United States.

Industrial use of wastewater is more common, and a variety of cooling, processing and wash-water applications are possible (55,56). The use of wastewater for make-up water for evaporative cooling systems is a potentially attractive option in an integrated power plant cooling and wastewater management system.

Several specific disposal alternatives are selected in this study for evaluation in an integrated management system. These are land application to agricultural crops, ocean discharge (outfalls to estuaries, bays or the ocean) and use of wastewater as evaporative cooling make-up. Much of the remainder of this chapter is devoted to an analysis of the land application alternative. Comparatively little information exists on land application on the sandy soils of northeast coastal areas, and an analysis of soil characteristics, application rates and impacts is necessary for a realistic evaluation. Suffolk County, Long Island is selected as an illustrative setting for land disposal.

The other two alternatives have received study elsewhere (17, 56,57), and their characteristics are outlined briefly in this chapter. Ocean disposal is included since it represents the conventional disposal method for coastal municipal wastewater systems. The cooling water make-up alternative is selected because it represents a closing of the water cycle in an integrated cooling/ wastewater management system. Wastewater is thus warmed by power plant waste heat and after treatment is injected into the cooling systems. In all alternatives wastewater is assumed to have undergone secondary level treatment (see Appendix Table 1) and is at temperatures of 65-80°F in winter and 85-100°F in summer.

A. WASTEWATER APPLICATION TO AGRICULTURAL CROPS

General

With availability of large amounts of agricultural lands, the irrigation of crops with secondary wastewaters can be an attractive disposal alternative. Crops may benefit both from the water and from wastewater nutrients. In passing over or through the soil, the wastewater can be sufficiently renovated to provide a high quality water for ground water recharge or surface water discharge. Irrigation methods include ridge and furrow, flooding, and spray application. The first two methods are generally applicable to "tight" soils with low infiltration rates or permeabilities (52,58), and spray irrigation is recommended for highly infiltratable, well drained soils (52,58,59). Wastewater irrigation areas are designed to prevent surface runoff, and all applied water in excess of plant needs (evapotranspiration) passes as seepage water through the soil into the ground water or is collected by underground drainage. A fourth application mode, overland runoff, is generally not classified as irrigation (58). With this procedure, which also requires impermeable soils, wastewater flows in a sheet over land planted with grass and is collected at the end of fields for further use or discharge. Spray irrigation is generally considered to be the most effective of the methods for renovating wastewater, and is the only method suitable for sandy soils which have high infiltration rates and are well drained. Since these soils are characteristic of northeast coastal areas, spray irrigation is the only application mode considered in this study.

When wastewater is applied to a soil/crop ecosystem a number of physical, chemical and biological processes take place which tend to remove contaminants from the water. These contaminants include suspended solids, soluble organic material, dissolved solids and pathogenic bacteria and viruses. Suspended solids are filtered by the soil and organic material is rapidly oxidized by soil micro-organisms. Irrigation with a secondary effluent will result in seepage water with insignificant suspended solids and BOD concentrations in most spray irrigation systems (52,58). Removal of dissolved solids is more difficult to predict, however, and will depend on soil type, crop cover and application rates. Wastewater dissolved solids consist chiefly of plant nutrients, salts and heavy metals.

Nitrogen and phosphorus are essential plant nutrients which are contained in wastewater. Nitrogen in secondary effluents is mainly inorganic, consisting of ammonium and nitrate. Ammonium may be adsorbed by soil clay particles and organic matter. Remaining ammonium is oxidized rapidly to nitrate which may subsequently be used by plants, or, in the presence of substantial organic material, immobilized in soil micro-organism growth. The principal mechanism for phosphorus removal from wastewater percolating through the soil is adsorption or "fixation" by clay minerals and iron and aluminum hydrous oxides (52,60). Although phosphorus is needed for plant growth, the amount required is small compared to the quantities contained in wastewaters or fixed by most soils. Nitrogen and phosphorus which are not removed by the above mechanisms will pass with seepage water into ground water aquifers. Although phosphorus will have no adverse effects on future use of ground waters, nitrogen, in form of nitrates, constitutes a definite health hazard, as noted earlier.

Common salts, such as sodium and calcium, are not significantly removed in the soil. The only mechanism for removal is cation exchange, but an equilibrium is quickly reached with solution concentrations resulting in little net removal from wastewater. Heavy metals, such as lead, copper, zinc and others, will be found in wastewaters containing industrial wastes. They are removed in the soil principally by adsorption by clay and organic matter. The common salts, by contributing to water hardness, can have adverse effects on certain warm water uses, but are not likely to result in significantly higher concentrations than normally occur in ground waters. Heavy metals are toxic to man and livestock as well as growing plants, and any introduction to aquifers which are used for water supply is potentially dangerous.

The removal of pathogenic or disease-causing bacteria and viruses from wastewater applied to the soil is poorly understood, but sunlight and adsorption by soil apparently contribute to the process. When wastewater is disinfected by chlorination prior to application, bacterial hazard is eliminated (55). Chlorination may not remove viruses, but percolation of the wastewater through soil will in general prevent viral contamination of ground water:

> "unless fissures or dissolution channels are present for organisms transport, percolation through even the coarsest soil will remove bacteria and viruses within a few to several feet (59, p. 49)."

Although ground water contamination from pathogens is not likely with spray irrigation of disinfected wastewaters, viruses may be transported from sprays as aerosols. This hazard can be controlled by spray equipment which results in large droplet sizes, buffer areas of up to 200 feet around the application area, and by avoiding spraying during high winds (58). If a crop is grown for human or animal consumption, viral contamination must be avoided by prevention of spraying for a period of time prior to harvest.

With knowledge of soil and crop characteristics, some prediction of the short-term performance of a land application system can be made. Long-term performance is most uncertain, particularly with respect to dissolved solids. Soil clay particles may be very effective in removing ammonium and heavy metals for an initial several years, but an equilibrium may be reached when the soil's capacity for such adsorption is reached (52).

Yields of most crops grown on land application areas can be expected to be comparable to crops receiving large quantities of irrigation water and commercial fertilizers. There is some evidence to indicate that orchard yields may be depressed by wastewater irrigation (61). In addition, nitrates and heavy metals may accumulate in plant tissues to levels toxic to humans and livestock. Metals may build up in the soil to concentrations which are toxic to plants well before the soil's capacity for adsorption is reached (52). It is clear that extensive monitoring of plants, soils and seepage water should be part of any land application system.

Ideal soil for a land application system is well drained, has an organic content in the neighborhood of 5% and contains as much clay as is consistent with good drainage. A crop which utilizes considerable nitrogen, such as hay or sod, corn, potatoes or leafy vegetables is desirable. Certain states have regulations applicable to wastewater irrigation of crops grown for animal or human consumption. Arizona, California and Oklahoma expressly permit irrigation of secondary, disinfected effluents on crops grown for human consumption, but a number of other states prohibit the practice. As of 1972, New York State had no laws or regulations prohibiting such irrigation (53). Northeastern climates limit the year round operation of land application even when heated effluents are used. Application is not recommended during freezing conditions, since ice formation will limit infiltration and biological activity. Problems of ponding, erosion, and freezing of equipment may also occur (52).

Land Application Example: Long Island

The agriculture of Long Island is confined principally to 60,000 acres in Suffolk County (Figure IV-1). The county is first in New York State in agricultural sales and has the most diversified agriculture in the state. High intensity production is prevalent with potatoes, cabbage, cauliflower, sod, and nursery products the most common crops. The county is also first in duck growing in the United States (11,62,63). In spite of its current health, agriculture's future in Suffolk County in not bright. Rapid land development and population growth have decreased acreage from 90,000 in 1960 to its current 60,000. It is projected that agriculture will vanish from Long Island by 1985 (12).

A combination of climate, soils and markets has contributed to Long Island's agricultural dominance. The frost-free season, which ranges from mid-April to late October, is the longest in the state (64). The agricultural soils are the sandy and silt loam Budd-Haven and Bridgehampton-Haven associations. These soils are well drained, level, and easily tilled (65). Normally, they would not be considered ideal agricultural soils because of their very low organic and clay contents. However, when irrigated and heavily fertilized, substantial yields of vegetable crops can result.

Several implications for land application of wastewaters can be drawn. Due to soil permeability, spray irrigation would be the indicated application mode. The low clay and organic matter content of the soils indicate low adsorptive capacities. Plant uptake is likely to be the only mechanism for significant nitrogen removal, and any wastewater nitrogen not utilized by plants would appear as nitrate in the ground water. Since ground water aquifers constitute Long Island's only water supply source (Chapter I), and nitrate contamination of water supplies can be a serious health hazard as noted earlier, the prevention of nitrate pollution must be considered the limiting factor in land application of wastewater.

Suffolk County agricultural crops require irrigation and high levels of fertilization. Spray irrigation with wastewater would accomplish the same purposes with much the same equipment, and hence is compatible with present operations. The only crops which can reasonably be considered for spray irrigation of wastewater on Long Island are potatoes and vegetables, both of which are grown for human consumption. Sod irrigation is possible, but Long Island's 3000 acres of sod

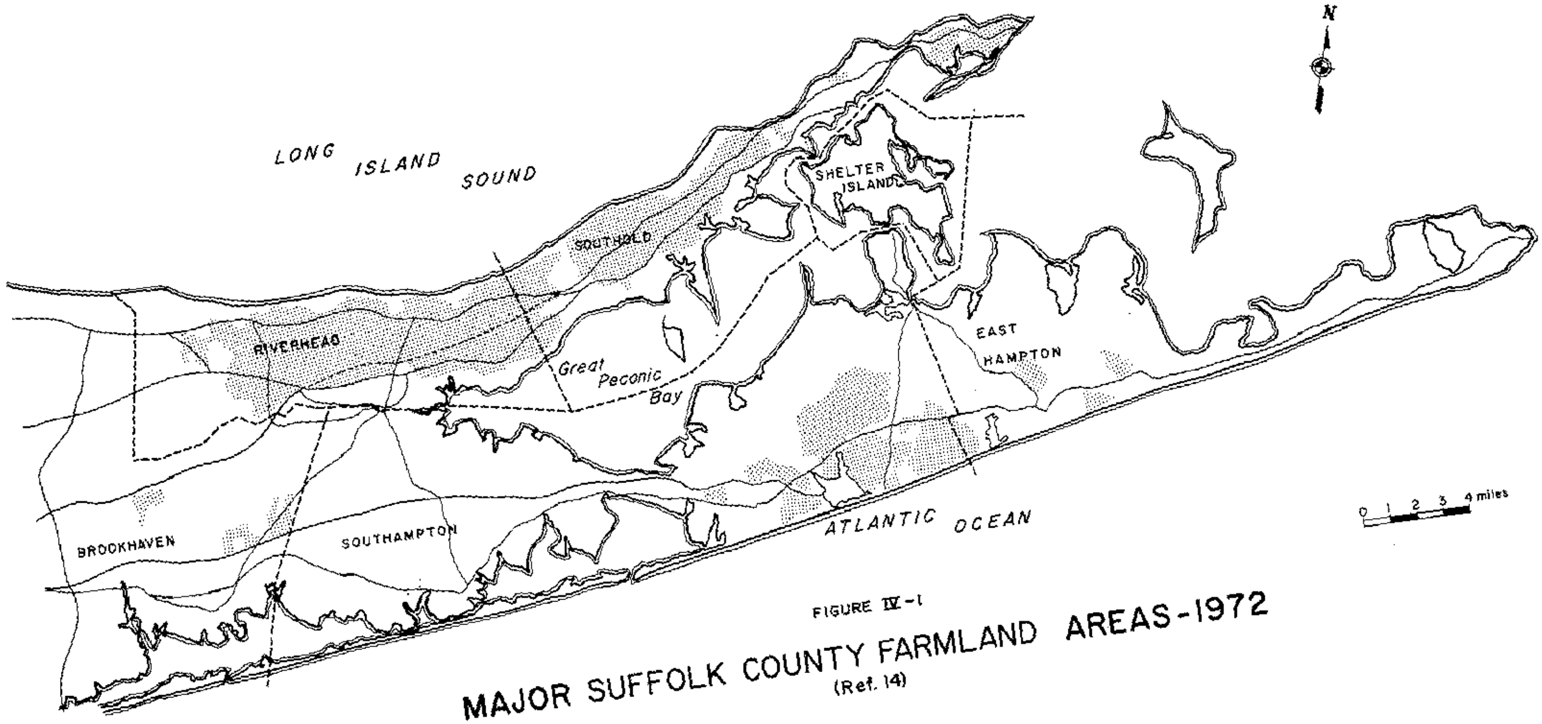

FIGURE IV-1

MAJOR SUFFOLK COUNTY FARMLAND AREAS-1972
(Ref. 14)

production are scattered in small tracts which would make distribution difficult. It is unrealistic to contemplate growth of lower value crops such as grains, silage and timber on Long Island's valuable and productive soils. The crops most suitable for spray irrigation of sewage are thus currently being grown in Suffolk County. Spray irrigation of a potato crop is shown in Figure IV-2.

Based on mean freeze-free periods for Long Island, an application period of seven months (April-November) can be anticipated. The growing season, which is the period of nitrogen utilization by plant growth, is considered to be May through September. Application rates for several Long Island crops are listed in Table IV-1. These rates are the maximum which would maintain a yearly average nitrogen concentration of below 10 mg/l in seepage water. This concentration is the Public Health Service standard for nitrate nitrogen in drinking water.

TABLE IV-1

MAXIMUM WASTEWATER IRRIGATION RATES FOR SELECTED LONG ISLAND CROPS

Crop	Nitrogen Removed By Crop (lb/ac)	Maximum Application (in/wk) April, October	Maximum Application (in/wk) Growing Season (May-September)
Potatoes	180	2	4
Cabbage	150	2	3
Cauliflower	150	2	3
Sod	180	2	4

It can be seen from the table that the highest application rates are possible during the growing season and that plant utilization of nitrogen determines growing season irrigation.

FIGURE IV-2

SPRAY IRRIGATION OF POTATOES WITH WASTEWATER

Based on these application rates, the characteristics of a spray irrigation system for wastewater disposal can be determined as shown in Table IV-2. Substantial winter storage capacity is required, ranging from 1500 million gallons at a 10 mgd wasteflow to 15,000 million gallons at 100 mgd. Substantial disposal areas are required, with larger areas required for crops with lower nitrogen requirements (cabbage, cauliflower). The acreages are available on Long Island, however. Even at a wasteflow of 100 mgd, less than half of Suffolk County's potato acreage is required (11). The last columns in Table IV-2 indicate that after crop water requirements are satisfied most of the wastewater is serving as ground water recharge. Details of the wastewater application analysis are given in the Appendix.

Several aspects of a land application system for Long Island cannot be predicted with certainty. For example, the agricultural benefits of the heat contained in a warm wastewater effluent are difficult to assess. As noted in Chapter II, artificial additions of heat can result in improved crop yields. If early spring wastewater applications can be timed to correspond to occasionally cold night time conditions, frost protection and increased early plant growth may be possible. Irrigation water must be applied very close to the soil surface, however, since much of the heat in a warm spray can dissipated to the air before the water reaches the soil (37,38). As was noted earlier, the quality of the seepage water entering the water table and the effects of heavy metals on the soil are additional long-term uncertainties. The quality, hygiene and marketability of crops grown for human consumption which are irrigated with wastewater are the final unknowns in the land application process.

Impacts

Disposal of wastewater through land application can be expected to have a wide range of impacts. In addition to the renovation of wastewater and recharge of ground water, the principal economic benefit of land application is the provision of nitrogen and irrigation water for crop growth. Major economic costs would include treatment and disinfection of the wastewater, a winter storage facility and transmission to the land application area. The latter will of course depend on the proximity of the wastewater treatment and storage system to the agricultural lands used for disposal.

Certain ecological impacts may result from the land application system. Insects, birds and small animals may be exposed to the wastewater sprays and the possibility of adverse affects on fauna cannot be completely discounted. The unnaturally wet conditions in

TABLE IV-2

CHARACTERISTICS OF A LAND APPLICATION SYSTEM FOR WASTEWATER DISPOSAL IN SUFFOLK COUNTY.

Average Waste-Water Flow (mgd)	Winter Storage Required (million gallons)	Land Disposal Area (ac)		Average Ground Water Recharge (mgd)	
		Potatoes, Sod	Cabbage, Cauliflower	Potatoes, Sod	Cabbage, Cauliflower
10	1500	1300	1600	10	9
20	3000	2600	3200	19	19
30	4500	3800	4900	29	28
40	6000	5100	6500	38	38
50	7500	6400	8100	48	47
100	15000	12800	16200	96	95

the irrigation area may encourage the growth of various insects, parasites and fungi which could impact the growing crop. The growth of weeds and other plants both within and bordering the cropping area would be stimulated by the wastewater irrigation and may require additional control. Possible adverse effects must be balanced, however, against the environmental impacts of alternative wastewater disposal methods (e.g., discharge to surface water bodies).

Water supply impacts of a spray irrigation system are beneficial, provided application rates are controlled to prevent ground water contamination. As seen in Table IV-2, land application results in nearly complete conservation of wastewater for reuse as water supply. Viewed as a water supply alternative, a 30 mgd land application system would deliver recharge water to the ground water at a cost of $0.25 - 0.30 per thousand gallons. This cost includes primary treatment, disinfection, and a lined, 1500 acre storage pond in Suffolk County. Transmission costs are not included but neither are any costs allocated to agricultural or wastewater management purposes. The cost compares favorably to the ground water recharge alternative described in Chapter I ($0.40 per thousand gallons).

The regional impact of wastewater irrigation on Long Island is related to the desirability of preserving open space and particularly, agricultural lands in Suffolk County. The use of such lands for wastewater disposal gives them, in effect, an additional valuable use. Municipalities could reimburse farmers for this use or purchase lands and lease them back to farmers for production of sewage irrigated crops. In either case, agricultural land becomes part of the region's wastewater management plans. The value of the land in multipurpose use or its municipal ownership may preclude conversion to urban or suburban uses. The result could be an economical and environmentally safe means of sewage effluent disposal, the augmentation of water supplies and the preservation of Long Island agriculture and open space.

B. OCEAN DISPOSAL

The discharge of treated wastewater to the ocean or to bays and estuaries is frequently considered the most economical and feasible method of disposal in coastal areas. On Long Island, for example, present and proposed wastewater management systems rely almost exclusively on coastal waters for disposal (17). The costs of this disposal method can vary greatly with location and environmental regulations, and no generalizations can be made concerning economic impact. However, the observation can be made that since populations and hence wastewater volumes are frequently concentrated near the coast, ocean discharge is often the most direct disposal method and hence may offer economic advantages over other methods which require long transmission lines to disposal areas.

Ocean disposal of wastewater will have profound effects on both water supply and environmental quality. The discharge of sewage to saline waters essentially converts municipal water requirements in the sewered area from a non-consumptive to a consumptive use. That is, water that previously may have passed through domestic use and into septic tanks and cesspools for leaching into ground water and subsequent reuse, now is mixed with saline water and can be reused only by passing through the hydrologic cycle by evaporation and precipitation on land areas. In rapidly developing areas such as Long Island which rely on ground water supplies, this diversion of recharge water not only limits ground water yields, but also may contribute to salt water intrusion into the aquifers (17).

The near shore coastal region is one of the most productive ecosystems known to man. Early life stages of many of the most commercially valuable fish and shellfish are spent there, and breeding grounds and homes of a variety of important wildfowl are also present. In addition, many small plants and animals which are at the bottom of aquatic food chains thrive in these coastal waters. The ecology of wetlands, estuaries and bays depends on a complex balance of fresh and salt water, nutrients, sunlight and diversity of species. The discharge of wastewaters to these areas or to the shallow ocean waters beyond will have both physical and biochemical effects on this ecology. The physical disruption of wetlands by sewer and treatment plant construction and the dredging and filling required for outfall construction will all have at least temporary adverse effects on natural populations. To the extent that dune areas are degraded by construction, the shoreline region may suffer increased erosion from wave action. The discharge of an effluent in the ocean or bay will produce a "boil" of fresh water, nutrients, organic and particulate material which will rise to the water surface. A heated effluent will result in a more pronounced boil due to the reduced wastewater density. With on-shore currents, wastewater constituents will move to shallow waters and beaches. The deposition of organic material and silt as sediment will change the sandy ocean bottom near an outfall and limit food sources for bottom grazing aquatic life.

In summary, ocean disposal of a wastewater effluent results in a loss of fresh water for further water supply use and a set of environmental impacts ranging from a temporary disruption of beaches and wetlands to the possible major disruption of a highly productive and valuable coastal ecology. In spite of these impacts, there are several compelling reasons for the traditional acceptance of this disposal alternative. First of all, water supply has not historically been considered a problem in the humid Northeast. Secondly, the environmental effects of ocean disposal were not traditionally considered severe, nor are they presently well understood. Finally, the large wastewater volumes produced in populous areas must be disposed of, and discharge to coastal waters is one of the very few demonstrated technical solutions to this disposal problem.

C. COOLING WATER MAKE-UP

The evaporative cooling systems of power plants which were discussed in Chapter II have substantial make-up water requirements (a minimum of 18 mgd of freshwater in the case of towers and spray ponds). The reuse of treated wastewater for make-up water is thus an obvious wastewater disposal method for an integrated power and wastewater management system. Moreover, since make-up water is a small fraction (2-3%) of the total cooling water flow, the heat contained in wastewater would have no adverse effect on cooling.

Treated municipal sewage has been used as cooling tower make-up in the United States since 1951 (70). Cooling water make-up constitutes the largest direct use of treated wastewater in the U.S. today (71). In spite of a history of past use (57,70,71) reuse of wastewater as make-up cannot be considered as either generally accepted or free from technical problems. Total U.S. use by steam electric power plants is only 15 mgd (70) and some previous users have discontinued the practice due to problems of corrosion and biological fouling (57). Some pre-treatment is required in all applications to control corrosion, fouling and slime growth. Results from pilot plant studies and the experience of the Burbank, California Municipal Power Plant indicate that problems can be controlled in individual cases with a "trial and error" pre-treatment program (57,71).

The impact on water supply of wastewater reuse for evaporative make-up will depend on the source of water supply which is replaced. If a cooling tower employs a high quality ground or surface water source which could also be used for municipal supply, then the substitution of wastewater will have a highly beneficial effect. Conversely, if present make-up is from a source not suitable or accessible for water supply, wastewater make-up may have no imapct on water supplies, and wastewater might be better utilized for other purposes which would tend to conserve or augment water supplies. In the balance, however, water conservation will in many cases be the strongest argument for wastewater use in cooling, and such use at present appears to be one of the most feasible means of wastewater recycling (55,71).

The possible adverse effects of the make-up water disposal alternative is limited to the possible transmission of viruses in aerosols from cooling towers and spray ponds. The application of the alternative is somewhat limited by the quantities of water involved. The make-up water requirement with a nuclear power plant is small compared to the sewage flow from a large city. However, population centers of moderate size (populations of 100,000 - 200,000) would produce adequate wastewater quantities for a 1100 MW plant.

CHAPTER V - PRELIMINARY SCREENING OF INTEGRATED MANAGEMENT SYSTEMS

An integrated system for power plant cooling and wastewater management consists of components for cooling, thermal enhancement of wastewater treatment and wastewater disposal (Figure I-4). Alternatives for each of these components have been evaluated in previous chapters, and the various ways of putting the alternatives together in unified management systems will now be outlined.

A. TECHNICALLY FEASIBLE SYSTEMS

There are countless ways of combining wastewater management and power generation either with each other or with other resource management alternatives. The motivation for studying such combinations is the evolution of systems which manage limited resources as wisely as possible. Only a fraction of such possibilities have been studied in any detail. Moreover, while there may be many conceptual alternatives for system integration, not all of these can be considered technically feasible. The limited alternatives which are outlined in this study are based on suggestions from previous studies, certain known or anticipated characteristics of power generation and wastewater management, and current levels of technology. Although this approach may be somewhat conservative, it assures that the alternatives which are presented have some likelihood of implementation without major disruption of established design and operating procedures.

Within this framework, a variety of conclusions relative to power plant cooling and wastewater management have been noted in earlier chapters:

1. Conventional wastewater treatment processes are temperature-dependent and the elevation of wastewater temperatures should enhance the efficiency of such treatment.

2. Steam generation of electrical power produces large amounts of waste heat, mainly through the condensation of process steam. Some of this waste heat, which is normally removed from condensers by large amounts of cooling water, can be transferred to wastewater.

3. Evaporative cooling systems such as towers and ponds which dissipate cooling water heat prior to recirculation through the condensers require significant quantities of make-up water to replace evaporative and blow-down losses. Wastewater is a possible source of such make-up.

4. Wastewater contains nutrients which can be utilized in plant growth. The irrigation of agricultural crops with sewage can provide both water and nutrients to a growing crop. If sewage is at an elevated temperature, a crop may benefit from this additional source of heat.

5. Evaporative cooling, waste stabilization and winter wastewater storage are possible complementary functions of a single, large cooling/stabliziation pond.

These observations have led to the selection of the alternative system components shown in Figure V-1.

Selection of alternatives is obviously not all-inclusive. Dry cooling towers and combination wet/dry tower systems are not included since experience with these alternatives is too limited to estimate performance or cost characteristics. Direct ground water recharge and industrial or municipal reuse of wastewater are feasible disposal alternatives which are not considered here since their application is highly dependent on wastewater and aquifer properties in the former case and on quality and quantity requirements for use in the latter.

These components are, of course, a subsystem of a total power and wastewater management system which would include the power plant and the required power transmission and wastewater collection facilities. These additional components are considered fixed in the study, and modification of power plant design and the utilization of unconventional or advanced waste treatment are not considered in detail.

With the options of fresh and saline water use in evaporative cooling systems, and including the possible alternative of no heat transfer to wastewater, there are a total of 84 combinations in Figure V-1. Not all of these are possible integrated systems, however, since certain combinations are either redundant or inconsistent. For example, a cooling/stabilization pond would not be used with open-cycle cooling. Elimination of similar possibilities produces 62 possible integrated systems for power plant cooling and wastewater management.

An evaluation of the technical feasibility of the above systems is not straightfoward. A simple and certainly naive examination would indicate that each system is technically possible; that is, any of the systems could be constructed and operated.

A more basic and relevant concern is the reliability of a system or the degree to which its technical performance is considered known. For example, the performance of a sectionalized condenser is uncertain since the heat transfer properties of untreated wastewater are unpredictable. If a condenser is sized and constructed anticipating a higher level of performance than is actually produced, the condenser would have to be redesigned at considerable expense. Predictability of technical performance must be considered a key element of technical feasibility.

COOLING ALTERNATIVES:

EVAPORATIVE TOWER (FRESH OR SALT WATER)	OPEN CYCLE (ONCE - THROUGH OCEAN WATER)	SPRAY POND (FRESH OR SALT WATER)	COOLING POND (FRESH OR SALT WATER)

TREATMENT ALTERNATIVES:

BAROMETRIC CONDENSER -ACTIVATED SLUDGE	SECTIONALIZED CONDENSER- ACTIVATED SLUDGE	COOLING / STABILIZATION POND

DISPOSAL ALTERNATIVES:

OCEAN DISCHARGE	LAND APPLICATION (SPRAY IRRIGATION)	MAKE-UP (FOR EVAPORATIVE COOLING)

FIGURE V-I

COMPONENT ALTERNATIVES FOR AN INTEGRATED POWER PLANT COOLING-WASTEWATER MANAGEMENT SYSTEM

In the analysis of complex systems it is traditional to screen systems for technical feasibility prior to an investigation of the degree to which technically feasible systems satisfy management objectives. The present systems are characterized by varying levels of technological uncertainty, however,and these uncertainties may be as critical in evaluation as the system's cost or other impacts. Accordingly, rather than eliminating certain systems on the basis of technical considerations, predictability of technical performance is considered a management objective which should be evaluated in addition to economic, environmental and water supply objectives.

B. SYSTEM EVALUATION

The four objectives of an integrated power plant cooling and wastewater management system are considered to be as follows:

1. Predictable or reliable technical performance.

2. Low financial cost.

3. Minimization of adverse environmental impacts.

4. Enhancement of water supply.

Several integrated systems have been selected for evaluation with respect to these objectives (Table V-1). While somewhat arbitrary, the selection is intended to indicate a range of systems which could be considered for Northeastern coastal areas similar to Long Island, The evaluations are not site-specific, and additional factors may need to be considered for a specific location.

TABLE V-1

SELECTED INTEGRATED COOLING/WASTEWATER MANAGEMENT SYSTEMS

System	Component: Cooling	Heat Transfer	Disposal
A	Open-Cycle	None	Ocean
B	Saline Tower	Barometric	Land
C	Saline Tower	Sectionalized	Land
D	Freshwater Tower	Sectionalized	Ocean
E	Fresh Water Spray Pond	Sectionalized	Make-up
F	Cooling/ Stabilization Pond		Land

The systems are rated in each objective category with (-) indicating that a system is one of the less effective in accomplishing the objective, (0) indicating an average or mid-range level of the objective, and (+) designating that the system satisfies the objective better than other systems. Factors which are considered in each objective category are summarized below.

Technical Performance indicates the degree to which system performance is certain or known. It should be noted that system uncertainties are centered on heat transfer and wastewater treatment and disposal. Limited field experience precludes the accurate prediction of treatment efficiencies at elevated wastewater temperatures. The possibility of radioactive contamination of wastewater when a barometric condenser is used and the uncertainty of heat transfer characteristics with a sectionalized condenser are principal difficulties with these alternatives. Condenser fouling and possible anaerobic pond conditions in addition to uncertain treatment efficiencies are problems associated with the cooling/stabilization pond. Land disposal uncertainties include the effects of heated wastewater on agricultural crops and the long run effects on crops, soils and ground water.

Costs are based on cooling system, waste treatment, and disposal monetary costs less any benefits anticipated from wastewater use. These benefits would include provision of make-up water for evaporative cooling or irrigation water and plant nutrients for agricultural crops. When land disposal is used, the cost of a winter wastewater storage pond is included.

Environmental Impacts attempt to measure the total adverse environmental impact of the system. This category includes the impact of thermal discharge to ocean waters and possible ecological disruption of coastal waters associated with ocean disposal of wastewater. Air pollution resulting from drift, salt deposition and fogging from evaporative cooling systems is also considered. Other areas of concern include public health and impacts on terrestial fauna and flora when land disposal is used.

Water Supply is an indication of net impact of a system on water supplies. Consumptive use of fresh water evaporative systems and ocean disposal of wastewater have unfavorable impacts while non-consumptive cooling, water reuse, and ground water recharge with land disposal have obviously favorable impacts.

The system ratings are given in Table V-2. Since the ratings are based on the limited quantitative and qualitative information generated in earlier chapters, they should not be considered definitive.

System A (Open-cycle/no heat transfer/ocean disposal) represents the conventional management option. There is no integration of cooling and wastewater treatment and no consumptive use of freshwater by cooling. Technical performance is well understood, and financial costs are the least of any system evaluated. Water supply impact is unfavorable, since ocean wastewater discharge precludes further water supply use. Severe adverse environmental impacts are due to thermal and organic pollution of coastal waters, as discussed in Chapters II and IV.

TABLE V-2

EVALUATION OF SELECTED INTEGRATED SYSTEMS

		Objective Categories		
System	Technical Performance	Cost	Water Supply	Environmental Impacts
A	+	+	-	-
B	-	-	+	0
C	-	-	+	0
D	0	+	-	0
E	0	+	0	+
F	-	0	+	+

KEY:

\+ Relatively favorable effect on objective

0 Mid-range effect on objective; average with respect to other systems

\- Relatively unfavorable effect on objective

System B (Saline cooling tower/barometric condenser/land disposal)has uncertain and potentially severe performance characteristics, with regard to treatment efficiencies and radioactive contamination. Cost of salt water cooling towers, boiler water make-up and winter wastewater storage make this system one of the most expensive considered. Since salt water make-up would be used for the tower, and land disposal would result in ground water recharge, net water supply impact would be positive. Environmental impacts are associated with drift, fogging and salt deposition, and possible radioactive contamination of ground water.

System C (Saline cooling tower/sectionalized condenser/land disposal) is similar to the previous system but is less costly since boiler water make-up is unnecessary. Moreover, performance uncertainties and environmental impacts associated with radioactivity are absent.

System D (Freshwater cooling tower/sectionalized condenser/ ocean disposal) represents a minor departure from the rankings of System A in most categories. The cost of a freshwater cooling tower is substantially greater than open cycle cooling. Thermal pollution of coastal waters by cooling discharge would be avoided. Water supply impacts are more severe than with System A, since freshwater make-up is needed. Additional performance uncertainties are associated with the sectionalized condenser.

System E (Freshwater spray pond/sectionalized condenser/ wastewater as make-up) avoids environmental problems except for drift and fogging. Technical performance uncertainties are associated with the sectionalized condenser and any difficulties involved in the use of treated wastewater in the remainder of the cooling system. Spray ponds are less costly than salt water towers, and since make-up water is supplied by wastewater, the system would result in no net consumption.

System F (Cooling/stabilization pond/ land disposal) has fewer adverse environmental impacts than the other systems. Since a complete integration of cooling, waste treatment, and winter wastewater storage is effected, substantial cost savings are achieved. Technical performance must be considered as at least as uncertain as Systems B and C. Water supply impact is not as favorable as Systems B and C, since evaporative losses from the pond will consume a portion of the wastewater volumes.

C. SUMMARY

The rating of alternative systems, as given in Table V-2 indicates the degree to which any system satisfies four different and conflicting objectives. Since no system is superior in all categories, the selection of a "best" system is not obvious. Moreover, other considerations may influence system selection. As was noted in Chapter III, construction and coordination of integrated management alternatives can be difficult and the degree of difficulty is not likely to be the same for each system. An additional factor is the power industry's increasing preference for multiple plant siting at the same physical location. All analyses and evaluations have been based on a single 1100 megawatt nuclear power plant. A second plant on the same site requires a second cooling system or one system which is twice as large. Further study may indicate many more objectives than those listed in Table V-2.

Based on the preliminary screening, System F, which is a cooling/stabilization pond combined with land application of wastewater, is selected for further evaluation for the Suffolk County area of Long Island. The selection is based primarily on the system's favorable environmental impact, moderate cost and generally beneficial impact on water supply. Sufficient quantities of agricultural and vacant land are also available in the county for siting of the power plant, pond and wastewater application area. Since the system's technical performance is somewhat uncertain, it is obvious that implementation must await further study and field scale demonstrations. The technical aspects of the integrated system are given in Table V-3. The system is shown in schematic form in Figure V-2.

A final note should be made concerning the systems evaluated in this Chapter. The use of waste heat in wastewater treatment is but one of a variety of possible beneficial uses. Other possibilities were outlined in Chapter II, and include soil warming, greenhouse heating and air conditioning, aquaculture and extension of bathing seasons. These alternatives could be employed with Systems A through F to utilize portions of the waste heat which are not transferred to wastewater. Such conjunctive use is limited only by the fresh or saline water characteristics of the cooling water. Soil warming may be used with either saline or fresh water, greenhouse heating and air conditioning requires freshwater, aquaculture requires either salt or freshwater depending on the cultivated species, and extension of bathing seasons is appropriate only for open-cycle ocean cooling water.

TABLE V-3

PHYSICAL CHARACTERISTICS OF AN INTEGRATED COOLING/WASTEWATER MANAGEMENT SYSTEM - COOLING/STABILIZATION POND AND LAND DISPOSAL

Nuclear Power Plant Size:			1100 MW
Heat Rejection at Condensers:			$7.5\ 10^9$ BTU/hr
Terminal Steam Temperature:			120°F
Cooling Water Flow:			850 mgd
Cooling Water Temperature Range:			25°F
Pond Area:			1500 ac
Pond Depth:	Maximum:		10 ft
	Minimum:		3 ft
Pond Volume:	Maximum:		4.9 billion gal.
	Minimum:		1.45 billion gal.
Pond Temperature:			
	January:	Cooling Intake	55°F
		Cooling Discharge	80°F
		Average	68°F
	July:	Cooling Intake	90°F
		Cooling Discharge	115°F
		Average	102°F
Average Wastewater Flow:			30 mgd.
Average Pond Overflow (Effluent for land application):			18 mgd
Wastewater Treatment:			Primary + Chlorination
Land Application Area:			2300 ac
Crop:			Potatoes
Application Rates:			
	April, October		2 in/wk
	May - September		4 in/wk
Ground Water Recharge:			17 mgd

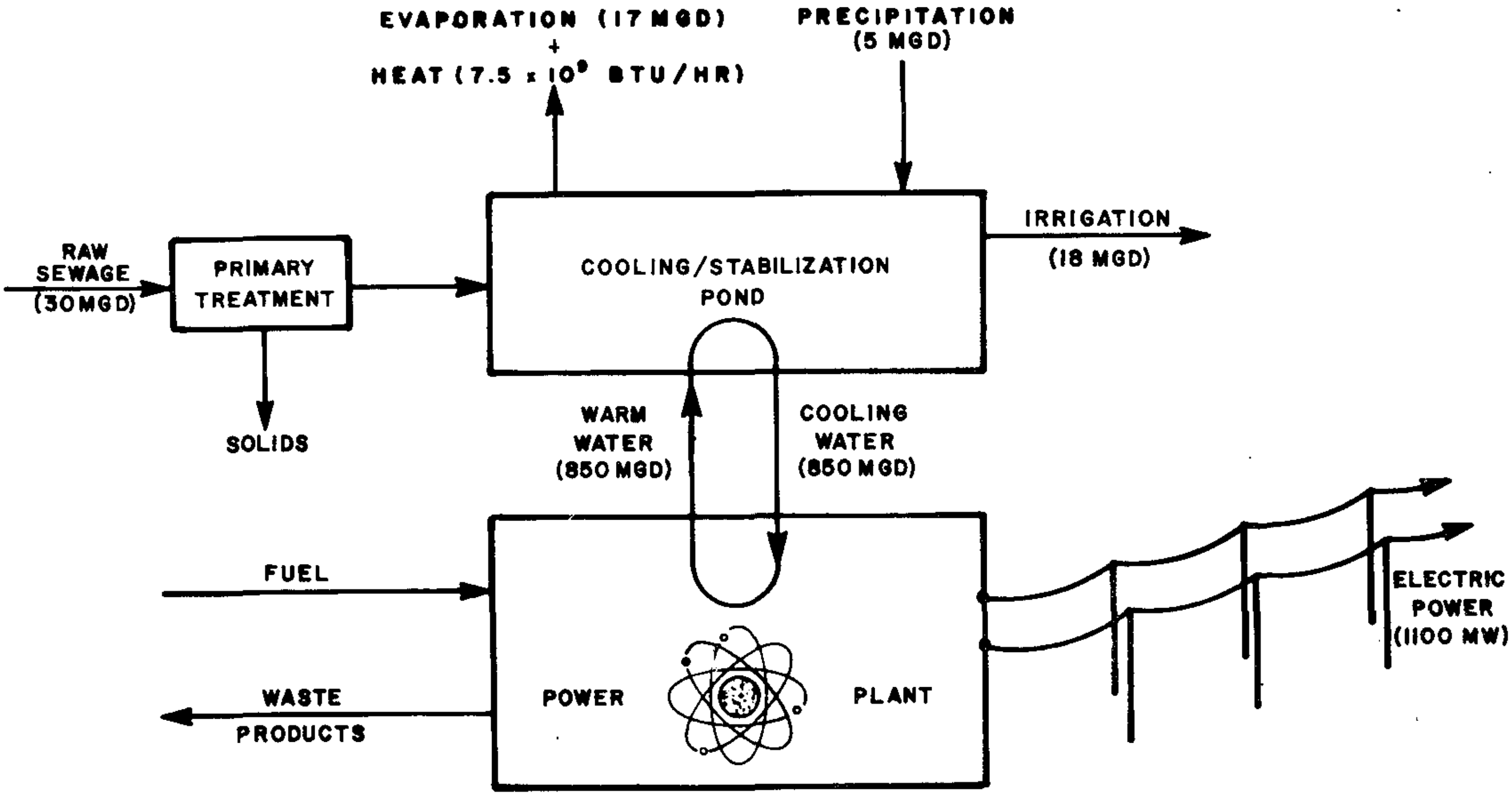

FIGURE V-2

MAJOR SYSTEM BALANCES
INTEGRATED SYSTEM F

CHAPTER VI - REGIONAL ANALYSIS OF AN INTEGRATED COOLING/WASTEWATER MANAGEMENT SYSTEM

An integrated management system consisting of a nuclear power plant, cooling/stabilization pond, primary wastewater treatment plant and land application area (Table V-3; Figure V-2, VI-1) has been analyzed for the regional setting of Suffolk County, Long Island.

The analysis consists of a summary of the benefits, costs, and impacts (both monetary and non-monetary) associated with the system. Three evaluation categories are included. Direct benefits and costs are associated with both the outputs of the management system (cooling, groundwater recharge, etc.) and the use of scarce resources (land, energy, etc.) by the system. Regional impacts are indirect benefits and costs related to regional economy and development. The final evaluation category is social and institutional impacts of the proposed system.

Impacts are dependent, to an extent, on the physical location of the management system. The power plant, pond and land application area will require a total of 4000-4500 acres, with an ideal location close to a proposed power plant site, wastewater sources and agricultural land. Examination of Figures I-2 and IV-1 indicates that such a site is not available on Long Island, and hence some compromise is necessary, requiring transmission lines for either cooling water, raw wastewater or irrigation water. Since the cooling water flow is so large (850 mgd), economy dictates that the power plant and cooling/stabilization pond share the same site. Furthermore, large areas of vacant or agricultural land are not contiguous to the major wastewater sources in Nassau and western Suffolk Counties. It is apparent that the most suitable location for the facilities (including the power plant) is in the agricultural areas of central and eastern Suffolk County. A substantial transmission line would be required for the raw wastewater in this case, but large transmission lines for cooling and irrigation water would be avoided. Location in an agricultural area would also provide the low population density with is desirable for nuclear plant siting. One possible location for the facility is in the town of Riverhead on the north fork of Long Island (Figure VI-2). The nearest major wastewater source is the Suffolk County Southwest Sewer District, which is expected to have a 1985 wastewater flow of 30 mgd. A 50 mile wastewater transmission line would be required, which could be located along the Long Island Railroad right-of-way.

A. DIRECT BENEFITS AND COSTS

Monetary Costs

The construction cost of the cooling/wastewater management system is estimated to be $46 million. This estimate is based on cost information from previous chapters and includes pond construction and additional power plant energy production as noted in Chapter II, primary treatment

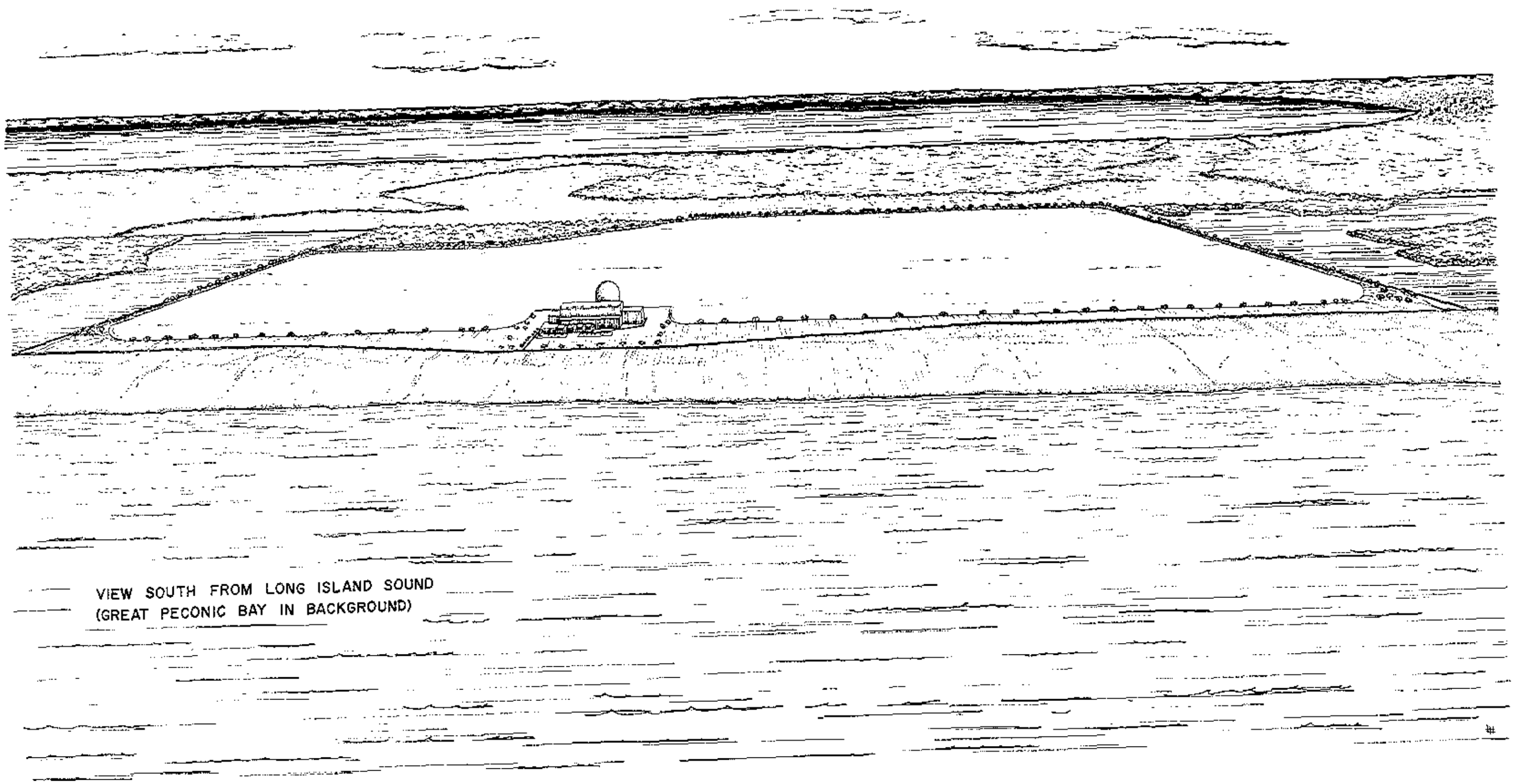

FIGURE VI-1

COOLING/STABILIZATION POND

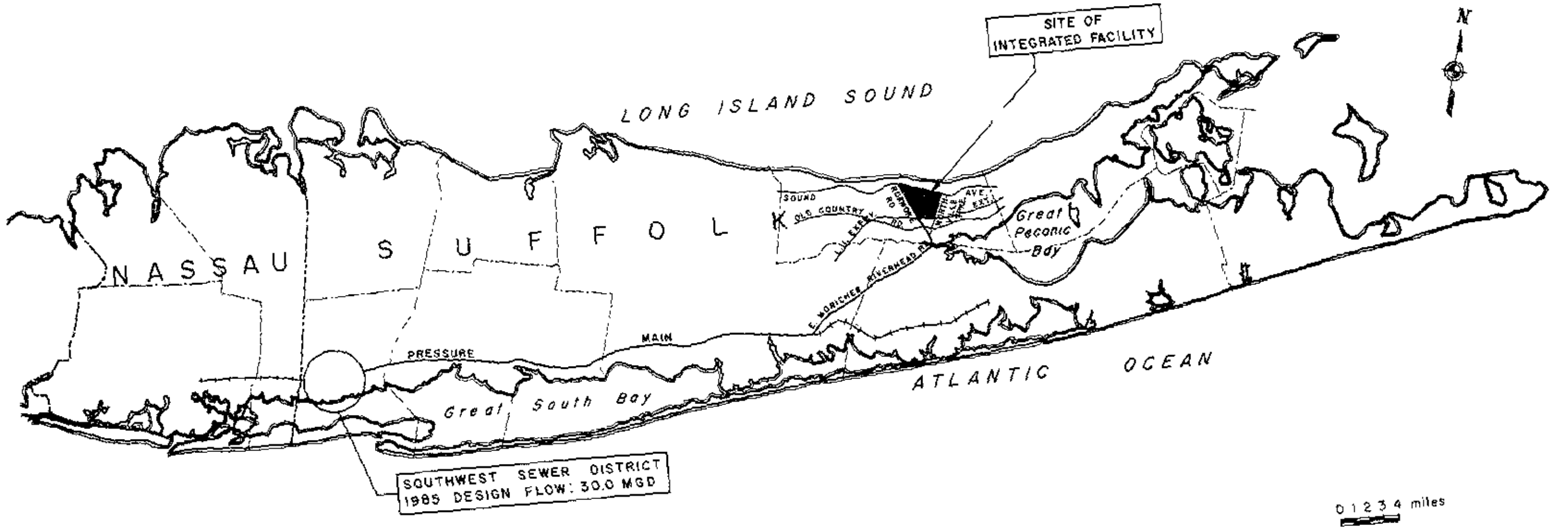

FIGURE VI-2

REGIONAL SETTING FOR INTEGRATED FACILITY and chlorination of wastewater and $16 million for a 50 mile transmission line and pumping station. Costs for spray irrigation equipment and land aquisition for the irrigation area are not included.

Environmental Quality

The environmental benefits of the proposed system are best evaluated by comparison with current or traditional methods for disposal of wastewater and thermal effluents in the Long Island area. Current practice is discharge to coastal waters with the attendant adverse environmental impacts noted in Chapters II and IV. With thermal discharges these impacts included entrainment, impingement and thermal shock of aquatic fauna, disruption of aquatic food chains and ecological changes associated with induced currents and mixing. Wastewater discharges may change the ecology of a coastal area by stimulating eutrophication, depletion of dissolved oxygen concentrations and formation of organic sediment deposits. These impacts are avoided with the integrated system since there is no discharge to surface waters. The environmental benefits of the system are thus the savings in environmental costs or damages that result when ocean discharges are eliminated.

Certain direct environmental costs or damages may be associated with the cooling/stabilization pond - land application alternative. The pond is essentially a highly eutrophic lake, and the adverse esthetic impact of algal growth and odors from anaerobic decomposition may be severe. Spray irrigation with disinfected wastewater will stimulate weeds and other undesirable flora and may encourage insect and microbial pests as well as plant diseases. Viral contamination of birds and small animals in the irrigation area is also possible. Over a period of years the irrigated soil may lose its ability to renovate the wastewater and could become sterile due to build up of salts and heavy metals. In this case, the land application area would have to be either abandoned or possibly renovated if contamination of ground water was to be avoided.

Water Supply

A net average groundwater recharge of 17 mgd would result from the spray irrigation of wastewater. This represents a conservation of 57% of the 30 mgd wastewater flow for possible reuse. The recharge is 4% of the total permissive sustained yield of Nassau and Suffolk County groundwater aquifers and 50% of the permissive sustained yield for the town of Riverhead (Chapter I, Table I-3).

By comparison, present wastewater disposal plans provide for ocean disposal, which provide no water supply benefits. Although the majority of the wastewater would be preserved for potential reuse by groundwater recharge with the proposed system, the value of such recharge will depend on the location and extent of water supply demands. If recharge areas already have sufficient yields for future demand and if transfers of water to areas with shortages are not possible, then the potential benefits of water supply augmentation will not be realized.

B. REGIONAL IMPACTS

Although the above summary includes the most obvious or direct benefits and costs of a proposed integrated system, such impacts are not the only nor even necessarily the most important effects of the projects on the Long Island area. The particular problems of rapid development and the need to preserve agriculture and open space on the Island were mentioned in Chapter I, and the cooling/stabilization pond-land disposal project should be evaluated with respect to these issues. Since a growing population requires increasing amounts of energy, water and wastewater treatment and disposal, the provision of these services will tend to encourage population growth and residential and commercial development. However, planned or controlled development can be facilitated by the location of sewer lines and the 6-7 square mile power plant, pond and land disposal area. Although the impacts of the system will depend somewhat on how it is implemented and on local and regional land use plans, several categories of impact on regional economy and development are summarized below.

Agriculture

If the system is located on agricultural land, the 4000-4500 acres required would constitute 7-8% of Suffolk County's agricultural area. However, 2300 acres of this total would be preserved in agricultural use. If the cooling/stabilization pond and power plant are located on contiguous non-agricultural land, the overall impact of the project would be a preservation of farmland. Such preservation would be consistent with a current program proposed to the Suffolk County Legislature (14).

Successful agricultural use of the land application area will depend on the cooperation of the present farm operators. Long term contracts or leases by a municipal authority or purchase of land by the authority and subsequent leasing to farmers will be necessary to insure that the irrigation area is not used for speculative purposes.

Impacts on the agricultural economy would depend heavily on the marketability of a crop irrigated with wastewater (potatoes, in this case). Without market acceptance, there are no agricultural benefits with the proposed system. Grass, natural vegetation or corn could be grown on the land application area, but little agricultural value would be associated with these crops.

Recreation

Recreation, tourism and the maintenance of vacation homes are important elements of Long Island's economy. By prevention of pollution of coastal waters by sewage and thermal discharges, the proposed project should preserve and enhance recreation opportunities. Moreover, by preservation of open land and construction of a small lake, the scenic value of the area will be enhanced. The potential also exists for direct recreation use of land incorporated in the system. With suitable buffering areas and/or by avoiding irrigation during weekends and holidays, hiking and bicycle trails in the cropping area and around the lake would increase recreation opportunities in the area.

Land Use

The immediate impact on land use would be the preclusion of future development on the 4000-4500 acres required for the project, thus preserving a large area of open space in a rapidly growing region. Additional land use effects would depend on local and regional land use regulation. As noted earlier, the provision of energy, wastewater management and water supply could stimulate commercial and residential growth in the area of the project, but the type and extent of development will depend on the region's policies and regulations governing land use. The significant point is that requisites for development are provided by the management system, but that the system itself will not dictate the form of development which takes place.

C. SOCIAL AND INSTITUTIONAL IMPACTS

The implementation of any resource management program results in a distribution of costs and benefits to individuals, groups and localities. The beneficiaries are likely to support the program while population segments bearing the costs may offer opposition. The social acceptance of a program is determined by the particular way in which advantages and disadvantages are distributed. With the power/wastewater/water supply system proposed in this study, the distribution of impacts depends on both location and the selection of an appropriate institution for implementation. Institutional considerations are particularly significant, since the distribution of economic impacts is very much determined by the nature of the managing institution.

If the cooling/stabilization pond and land disposal facility could be operated successfully in an area such as Suffolk County, benefits would accrue to a variety of interests. A power company would have a nuclear plant site and cooling system; municipal sewage treatment authorities would obtain a 30 mgd wastewater management system; farmers would be provided with irrigation water and crop nutrients; water supply companies and well owners would have their supplies augmented; and the public would benefit from preservation of open land in a rapidly developing area and the prevention of thermal and organic pollution from cooling and wastewater discharges. This long list of beneficiaries creates paradoxical difficulties. If only one party benefitted from the system, that party might implement the project, provided returns exceeded costs. Unfortunately, the wide distribution of benefits results in total returns greater than total costs but no party's benefits are sufficient for it to construct the system unilaterally.

Furthermore, the technological uncertainties associated with the system may constitute a higher level of investment risk than any one group is willing to undertake.

One possible solution to this problem is public construction and ownership with appropriate charges to users. Such an approach may not be appropriate, however, since power generation, agriculture and frequently water supply are generally in private ownership. Moreover, public ownership would remove a large land tract from tax rolls and likely generate local opposition to siting. At the other extreme, the system could be wholly privately owned by the power company. In this case, local tax revenues would be augmented, thus increasing local acceptance for siting. Two substantial drawbacks exist, however. The power industry is subject to intense regulation, and the reaction of regulatory agencies to a power company's investment in wastewater management and irrigation facilities may not be facorable. Secondly, sewage treatment and disposal, which is vital to the public health and environmental quality of a community, would depend on facilities owned and operated by a private group with management objectives and expertise in an area quite removed from wastewater management. A third alternative would be a combination of public and private ownership. The nuclear plant facility and site would be owned and operated by a power company and the cooling/stabilization pond would be owned by the power company and regional wastewater authority. The latter would also construct and operate the primary treatment plant and raw wastewater and irrigation transmission lines. Finally, spray irrigation of agricultural land could be by contractual agreement with farmers. This arrangement would insure that all management objectives are considered adequately and should minimize reductions in a locality's tax base.

Other variations of these institutional arrangements are possible, and selection will depend on regulatory agencies, statutory authority, and the willingness of relevant interests to cooperate with one another. Any institutional arrangement will result in a distribution of costs and benefits through changes in local tax revenues, and this may in turn determine local acceptance to the siting of the proposed system.

In addition to the economic impacts associated with property taxes, the location of the management system will result in other distributional effects which will influence social acceptance. If wastewater is transported from one locality to a cooling/stabilization pond in another area, the locality obviously avoids any adverse environmental effects associated with wastewater disposal, and hence benefits from the scheme. Conversely, the area in which the pond and disposal area are sited is subject to the adverse environmental effects noted earlier. When added to the normal concern over nuclear power plants, local opposition may occur. A balancing effect is the provision of additional groundwater supplies and preservation of open space in the siting area. The latter impact will, of course, generate opposition from developers and property owners who fear diminished land values.

A final area of social concern relates to the regional nature of the proposed system. Realistically, the project must be viewed as a regional management system which goes across the local political boundaries of towns and communities. Since electrical energy production is linked by transmission networks to other counties, states and even nations, the degree of local control over the management system cannot be large. While certain groups and interests favor a regional approach to resource management, other groups and interests wish to retain local management, where possible, of the services and facilities which impact them. Since any arrangement for project implementation will have varying levels of regional and local control, the regional-local issue will generate social conflict.

D. RESOURCE MANAGEMENT IMPLICATIONS

The integration of power plant cooling, wastewater treatment and water supply in a single management system can set a precedent for resource management in the Northeast. It could thus demonstrate that a range of resource development and conservation problems are amenable to solution through joint, complementary management. Moreover, if the project is successful, favorable direct impacts would result in each of the system's resource areas. Energy production would be facilitated by provision of a nuclear plant site and an environmentally safe means of heat rejection. The wastewater management problem shifts from a concern with treatment and disposal to an emphasis on reuse for cooling, agriculture and municipal water supply. Finally, water supply would be seen as not only the provision of wells, reservoirs and distribution systems, but also the conservative management of water in its varied uses.

The proposed management system represents an application of resource management policies expressed in the Federal Water Pollution Control Amendments of 1972, which call for management "which results in integrating facilities for sewage treatment and re-cycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges (PL92-500, Section 201 (e))".

It is becoming increasingly obvious that single objective or single group management of natural resources may be inefficient, result in environmental degradation and in general produce effects which are not in the public interest. It is equally evident that although joint management of resources may produce significant advantages, it is not a conventional approach. Thus, integrated systems such as those proposed in this study have yet to be demonstrated, and an evaluation of impacts must be based on considerable conjecture. This is neither a surprising nor necessarily negative observation; rather, it is an indication of the efforts which lie ahead for enlightened partnerships of private and public groups with responsibility for managing our finite resources.

To an extent, many of the uncertainties about the performance and impacts of a joint management system can be resolved by programs of further study and demonstration. Several programs are outlined in the next chapter.

CHAPTER VII: FURTHER STUDY AND DEMONSTRATION

The contiguous or integral siting of power generation and wastewater treatment facilities would allow coordinated management of the land, water and energy resource elements normally associated with these utilities. The technical linkages among the elements of heat dissipation, wastewater treatment and water supply augmentation are such as to allow a variety of alternative plans to achieve these benefits. In all cases, however, a demonstration of the extent to which these technical linkages can be achieved is necessary. These linkages have been reviewed (Chapters II, III, & IV) and summarized (Chapter V). Uncertainties regarding technical performance and feasibility have been noted and it is appropriate to conclude this study with a realistic assessment of the importance of technical linkages, the uncertainties currently surrounding them and an indication of alternative programs for further investigation and demonstration.

A. TECHNICAL LINKAGES

The significance of the integration mechanisms for cooling, wastewater and water supply management can perhaps best be seen by reference to each resource area: land, water, and energy.

Land

The sharing of a single site by utility management facilities can minimize land use disruptions and facilitate orderly development by preserving open land. This latter benefit derives from the site consumption requirements of power plants, especially those using nuclear fuel, and the site requirements for water supply augmentation using land application of treated wastewater.

Establishment of several technical linkages will increase the amounts of land involved. The first of these is the conjunction of power plant cooling and waste stabilization through the provision of a cooling/stabilization pond. There has been no field experience with such a facility, however, and the required pond configuration, cooling performance, degree of pre-treatment of wastewater necessary, effluent quality and the aesthetic aspects of the pond cannot be predicted with certainty.

A second linkage is between wastewater management and water supply through land application of treated wastewater to vegetable crops and subsequent recharge of ground water or through land application solely for recharge purposes. The feasibility of this linkage is more predictable, since land application systems have seen successful implementation. However, review of relevant literature has not indicated whether or not performance would be satisfactory on the sandy soils of humid coastal regions with crops grown for human consumption.

Finally cooling, wastewater treatment and water supply can all be connected by the provision of winter storage of wastewater in the cooling/stabilization pond prior to land application. The additional uncertainty involved in this alternative is the effect of a large seasonal variation in pond depth on both cooling and waste stabilization.

Water

The technical linkage most relevant to the water resource is the use of suitably treated wastewater for make-up in evaporative cooling systems, thus integrating cooling, wastewater and water supply management. This alternative has been successfully applied with cooling towers (Chapter IV) and although the levels of additional chemical treatment required for the make-up water will frequently be arrived at by trial and error, field experience has shown technical feasibility. Effects of wastewater use in cooling ponds and spray ponds is less certain however, since the problem of algal growth and the subsequent impact on power plant condensers has not been investigated. This problem is also of relevance in a cooling/stabilization pond.

A second water-related linkage is the recharge of ground water supplies by land application of wastewater. The principal water resource uncertainty with the land application alternative is the long-term ability of a sandy soil to remove nitrates and heavy metals from treated wastewater before it enters the ground water.

Energy

Conservation of energy resources through integrated management can be accomplished by technical linkages which utilize waste heat for beneficial purposes. There are two such connections between power plant cooling and wastewater management. The first of these is the transfer of waste heat from power plant condensers to a wastewater treatment plant, thus increasing treatment efficiency. Although the improvements in efficiency from this thermal enhancement can be estimated by standard design formulae, field experience with heated wastewater is so minimal that these improvements must be considered unpredictable. Moreover, the mechanisms for heat transfer, the desired temperatures for various treatment processes, new process developments, and the selection, configuration and operation of the processes all require laboratory and field type investigations.

The second utilization of waste heat in wastewater management is spray irrigation of heated wastewater, resulting in potential improvements in crop yields by spring frost protection. Such benefits will depend on development of an irrigation method for permeable soils which prevents the wastewater heat from being dissipated to the air before reaching the soil.

The technical linkages between cooling, wastewater and water supply management are summarized according to resource area in Table VII-1.

TABLE VII-1

TECHNICAL LINKAGES FOR INTEGRATION OF COOLING, WASTEWATER AND WATER SUPPLY MANAGEMENT

Resource	Technical Linkage	Cooling	Wastewater	Water Supply	Need for Study And Demonstration
Land	Common Site	X	X	X	No
	Cooling/Stabilization Pond	X	X		Yes
	Land Application of Wastewater		X	X	Yes
	Combination of all of the above	X	X	X	Yes
Water	Wastewater as Cooling Make-up	X	X	X	Towers - No Ponds - Yes
	Land Application of Wastewater - Groundwater Recharge		X	X	Yes
Energy	Thermal Enhancement of Wastewater Treatment	X	X		Yes
	Land Application - Heated Wastewater	X	X		Yes

B. STUDY AND DEMONSTRATION PROGRAMS

Implementation of a prototype integrated resource management system which incorporates the technical linkages listed in Table VII-1 would involve substantial risk at this time. This risk can only be reduced by resolution of technological and performance uncertainties and development of guidelines for system design and operation. Several options are available for accomplishing this goal and can be arranged in order of descending calendar time requirements but increasing budget requirements as follows:

1. Investigation of Existing Facilities
2. Process Development Investigations
3. Demonstration Scale Investigations

In view of the lengthy time requirements for securing regulatory approval of power plant siting, options which minimize time consumption are necessary. However, because of the current state of the art, options which minimize calendar time consumption are those which require extensive laboratory and/or field scale testing. Thus, acceleration of further studies will require options which progress into the detailed testing phase prior to a clear identification of each of the results sought. In view of the potential environmental impacts of an integrated siting, documentation of negative and positive results should be considered by resource planners.

A program for each option is summarized below:

Program 1: Investigation of Existing Facilities

A one year study consisting of field observations and site visits at cooling, wastewater treatment and land disposal systems, which have characteristics similar to the proposed systems, may produce useful results and reduce the need for further demonstration. For example, certain food processing wastewaters are both warm and high in organic material. Observation of existing treatment processes for these wastes may provide guidelines to the efficiencies that can be expected in the treatment of municipal wastewaters. Similarly, cooling systems (condensing and non-condensing) which utilize heavily polluted water could provide insight to potential fouling and corrosion problems.

Indications of cooling/stabilization pond performance would be obtained from investigation of Lake Brauning, a cooling pond in Texas which uses polluted river water for make-up (6,72). Characteristics of land disposal of wastewater on sandy soils could be obtained from detailed review of on-going projects such as those at the U.S. Army Cold Regions Research and Engineering Laboratory (73) and at Brookhaven National Laboratories (19).

It should be emphasized that current literature does not provide the necessary guidelines for integrated management of cooling and wastewater systems. The motivation for field investigations and site visits is to elicit information and data which has not yet been reported. Since the value of this information cannot be predicted in advance, there is no assurance that this program would obviate the need for further study and investigation. Moreover, the program is not likely to produce extensive information on land use implications of integrated management systems.

Program 2: Process Development Investigation

A one year investigation program could have two components: Laboratory studies of wastewater treatment processes and the development of a mathematical model of a cooling/stabilization pond. Laboratory studies would most likely be focused on extension of previous work on the activated sludge process (43) and on processes for nutrient removal. Parameters to be considered include performance at various temperatures and the effects of time-varying wastewater and heat loads.

The value of these studies would be a determination of the theoretical limits of efficiencies which could be achieved by thermal enrichment of wastewater treatment. Although design and operating characteristics of prototype systems could not be developed from laboratory work, such studies could indicate the most fruitful avenues of pursuit in subsequent pilot or demonstration projects.

A mathematical model of a cooling/stabilization pond could be used to simulate pond performance under various design and operating conditions. An indication of optimum performance could thus be obtained. The usefulness of an unvalidated model is limited, however, and a model would be most appropriately used in conjunction with a cooling/stabilization pond demonstration project which would provide data for validation.

Program 3: Demonstration Scale Investigations

The development of design and operating guidelines for a cooling/stabilization pond and/or a thermally enriched wastewater treatment plant should be approached through a demonstration project. The goals of a project would be the establishment of waste treatment and cooling performance of a pond, the identification of heat transfer coefficients and corrosion rates of condensers, and the delineation of performance efficiencies for primary and secondary wastewater treatment.

A demonstration scale investigation would be the most appropriate alternative to minimize the total calendar time requirements to translate the planning concept into an implementable resource management design or to conclusively demonstrate that the indicated technical linkages cannot be fully realized. From a technical standpoint a demonstration scale investigation would also significantly enhance the results of the process development studies.

It is recommended that further testing of the concepts developed in this study be undertaken on a demonstration scale and that the design of demonstration facilities be such as to allow the flexibility of operation required for process development investigation. A proposed project and project budget are outlined in Tables VII-2 and VII-3.

The physical characteristics of the demonstration project are indicated in Table VII-2 for three different project sizes, corresponding to wastewater flows of 0.1, 0.5 and 1.0 mgd. The selection of an appropriate scale for the demonstration should be considered as a segment of demonstration project design. Larger scale projects may, of course, be more indicative of the performance of prototype systems. A secondary treatment plant is provided with separate primary and activated sludge units so that either primary or secondary wastewater effluent can be directed to the pond. A two-year program is suggested, in order to provide flexibility in the study of pond performance and, if desired, the effects of heat transfer to the treatment plant. The pond is sized to accommodate one-half of the wastewater flow.

The physical characteristics of the project are indicated in Table VII-2.

TABLE VII-2

PHYSICAL DIMENSIONS OF ALTERNATIVE SCALE DEMONSTRATION PROJECTS

Wastewater Flow: (mgd)	0.1	0.5	1.0
Pond Size: (acres)	2.5	12.5	25
Cooling Flow: (mgd)	1.4	7.1	14.2
Condenser Heat Rejection: (10^6 BTU/hr)	12.5	62.5	125
Condenser Area (ft^2)	950	4700	9500
Total Land Required (acres)	5	15	30

TABLE VII-3

BUDGET ESTIMATES FOR TWO YEAR DEMONSTRATION PROJECT

Wastewater Flow (mgd)	0.1	0.5	1.0
Construction Cost			
Pond (including land and lining)	$ 105,000	$ 330,000	$ 630,000
Wastewater Treatment Plant	300,000	770,000	1,260,000
Boiler, Condensers, Piping, Pumps	35,000	150,000	300,000
Maintenance Building, including laboratory	50,000	100,000	100,000
Sub Total	490,000	1,350,000	2,290,000
Engineering & Contingencies @ 1/3	170,000	450,000	770,000
TOTAL	660,000	1,800,000	3,060,000
Operation and Maintenance (2 years)			
General O&M	90,000	250,000	440,000
Scientific and Technical Personnel	110,000	200,000	200,000
Data Documentation & Reports	110,000	150,000	150,000
Fuel for Heat Source	170,000	820,000	1,640,000
TOTAL	480,000	1,420,000	2,430,000
PROJECT TOTAL	1,140,000	3,220,000	5,490,000

A project budget has been estimated based on location in Suffolk County, Long Island. This estimate is not a detailed design budget, but is intended to give an order of magnitude cost for the project. The budget is summarized in Table VII-3, for the three alternative project scales. It should be noted that the budget estimates include substantial costs for fuel. These are based on the production of heat sufficient to warm the cooling water flow 25°F and a fuel cost of $\$150/10^6$ BTU. It is assumed that the pond will be receiving a cooling water discharge during 50% of the project's two-year period of operation. A significant reduction in project cost could be realized by integration with an existing heat source (such as waste heat from an existing power plant).

Program 4: Demonstration of the Long-Term Performance of Land Application

There is apparently little experience with land application of wastewater on a vegetable crop such as potatoes grown on sandy soils in humid temperate climates. Thus the crop quality, the long-term ability of the soil to remove nitrates and heavy metals, and the possible build up of plant toxicants in the soil are unknown. A demonstration project covering at least a five-year period should resolve these uncertainties. Relevant operating parameters are application rates and wastewater treatment levels prior to application. Monitoring of crop yields and quality, quality of seepage water, and chemical and physical soil characteristics will be required. The project could also involve experimentation with irrigation timing and application mode to determine the beneficial effects of heated wastewater on crop yields.

Since a variety of land application studies have been conducted, it would probably be most economical to utilize existing institutional facilities for the project. This project could also be implemented in conjunction with Program 3, thus providing a disposal mechanism for wastewater effluents. Minimum land requirements for disposal of 0.1 mgd to 1.0 mgd of wastewater range from 15 to 150 aces.

C. IMPLEMENTATION

The programs of study and demonstration outlined above represent options for resolution of technological uncertainties. The options serve different purposes, however, and are by no means mutually exclusive. In fact, a strong argument can be made for simultaneous implementation of all four programs. Certain relationships between programs should be noted. Program 1 is probably most likely to yield useful results in the land application area, thus possibly eliminating the need for Program 4. Programs 2 and 3 constitute a complementary package particularly with regard to optimal design and operation of a cooling/stabilization pond.

Since implementation of a prototype integrated cooling and wastewater management system will require cooperative joint efforts by public and private groups, it is reasonable to suggest that the studies and demonstrations required to resolve technological uncertainties be a similar effort. Co-sponsorship by public or private institutions involved in power, wastewater and water supply management could provide the basis for institutional arrangements necessary for prototype implementation. In this fashion, demonstration projects would have significance beyond their technical results. Institutions, agencies and groups with concern for a range of resource problems could thus demonstrate their willingness to cooperate in joint resource management programs which benefit their own interests as well as those of the general public.

APPENDIX: TECHNICAL ANALYSES

A. COOLING SYSTEM COST ESTIMATES FOR CHAPTER II

General

Basic data for cost estimates are abstracted from Ref. 5 and 25 adjusted for a 1100 MW plant and an ENR index of 1400. Capital cost for energy production associated with each cooling system is determined by estimating the total of (i) cooling system energy requirements and (ii) the lost electric generating capacity for systems other than once-through cooling. The nuclear energy portion and turbogenerator capacity of a 1100 MW power plant is increased so that 1100 MW would be delivered to the transmission system (busbar power) after cooling power requirements and efficiency losses are accounted for. All system costs are scaled to an 1100 MW busbar power by a factor of capacity ratio to the 0.7 power. Turbogenerator and nuclear energy production for a 1100 MW plant have capital costs of $15,800,000 and $160,800,000, respectively (5).

Natural Draft Tower

Capital costs are from Ref. 25. Make-up water requirements assume a drift=0.2% of circulating water, heat dissipation due to the evaporation of 80% and number of concentrations of dissolved solids = 20. Salt water cooling capital costs are somewhat arbitrary, since Ref. 25 indicates only an approximate increase of 25% over freshwater systems.

Spray Ponds

Minimal cost information is available on large spray ponds. Cost estimates are based on the following assumptions:

1. Land improvement (construction) costs for spray ponds are equal to those of a cooling pond.

2. Sufficient land is available on the power plant site to accommodate the spray pond.

3. Pump, conduit, condenser and auxiliary capital costs are equivalent to those of a natural draft cooling tower.

4. Power requirements are equal to those of a cooling pond plus the energy required for spray module operation (27).

5. Evaporative losses are identical to those of a natural draft cooling tower.

6. Salt water spray ponds are 25% more expensive than freshwater spray ponds.

Cooling Ponds

The performance of a cooling pond varies with climatic regions and pond design (27). In the Northeast, low evaporation rates usually necessitate fairly large pond areas. The performance of a shallow cooling pond can be estimated from the following (28):

$$\frac{T_i - E}{T_o - E} = \frac{\exp(-r(2D-1))}{D-(D-1)\exp(-2r/(2D-1))} \qquad (1)$$

$$r = \frac{KA}{sCQ} \qquad (2)$$

where T_o = Temperature of heated cooling water discharged to pond(°F)

T_i = Temperature of cooling water leaving pond for condensers (°F)

E = Natural equilibrium temperature of Pond (°F)

D = Dilution of cooling flow due to mixing (D=1 indicates no mixing, or plug flow)

A = Pond area (acres)

K = Heat exchange coefficient (BTU/ft^2-day-°F

s	=	specific weight of cooling water (lb/ft^3)
C	=	specific heat of cooling water (BTU/lb-°F)
Q	=	cooling water flow (ft^3/day)

Pond conditions are evaluated for the Long Island area for the months of January and July based on values of K and E determined from (29). Since a real pond will most likely approximate neither plug flow or perfect mixing, an intermediate dilution parameter of D=5 is used in equation (1). Several different pond sizes were investigated, and a final area of 1500 acres was selected as the minimal size for adequate cooling. Such a pond would have an effluent temperature of 55°F and 90°F in January and July, respectively. Average annual evaporation of 17 mgd is estimated from (29).

Pond costs are obtained from (25) with additional costs for land acquisition and pond lining. 1973 land prices for undeveloped tracts on Suffolk County are approximately $5000 per acre (New York Times, Oct. 16, 1973). Artificial pond lining with 20 mil PVC is estimated to be $1.10/sq. yd., installed. At an ENR index of 1400, land costs are thus $5,400,000 and lining costs are $5,800,000.

B. HEAT TRANSFER METHODS FOR THERMAL ENHANCEMENT OF WASTEWATER TREATMENT

Barometric Condenser

Heat transfer characteristics are based on the following (44):

$$q_w(t_2-t_1) = q_s(h_s-h_f) \tag{3}$$

where	q_w	=	Cold water flow into condenser (lb/hr)
	q_s	=	Steam flow (lb/hr)
	t_2	=	Temperature of warm water flow from condenser (°F)
	t_1	=	Temperature of cold water flowing into condenser (°F)

h_s = Steam enthalpy (BTU/lb)

h_f = Enthalpy of heated water (BTU/lb)

A (wet) steam temperature of 120°F is assumed.

Sectionalized Condenser

Condenser surface areas were determined by the basic heat transfer equation (44).

$$q_w(t_2-t_1) = U\ A\ T_m \qquad (4)$$

where q_w, t_2 and t_1 are defined as in equation (3) and

U = Heat transfer coefficient (BTU/hr - ft^2-°F)

A = Condenser area (ft^2)

T_m = Log-mean temperature difference (°F)

The heat transfer coefficient is given by

$$U = (R_{fc} + R_{sc} + R_w + R_{sh} + R_{fh})^{-1} \qquad (5)$$

where

R_{fc} = Cold fluid film resistance

R_{sc} = Cold fluid fouling resistance

R_w = Metal tube wall resistance

R_{sh} = Hot fluid fouling resistance

R_{fh} = Hot fulid film resistance

A cooling water velocity of 3-4 feet per second and 22 BWG 304 SS 1" OD tube condenser material is assumed (5). Values for R_{fc}, R_w, R_{sh}, and R_{fh} of 0.00094, 0.00025, 0.0002 and 0.0003 are used (5). R_{sc} is varied as described in Chapter III. An installed unit cost of \$12.40/ft^2 (5, Appendix B) is used to determine condenser costs.

Cost Estimates for a 50 mgd Treatment Plant

Cost estimates for a 50 mgd activated sludge wastewater treatment plant have been determined in Ref. 5 for both unheated and heated wastewaters. With some modification, these costs are applicable to the present study. Necessary modifications are as follows:

1. All costs are adjusted to an ENR index of 1400.

2. Costs of a raw water pump station and an ocean outfall for sewage effluent which were included in (5) are eliminated.

3. Costs of chlorination are added to the estimates for heated treatment plants.

4. It is assumed that a separate administration building would be required for the treatment plant even when the treatment and power plants are on the same site.

With the above modifications, cost estimates from Tables 15-20 in Ref. 5 can be used directly to determine costs given in Table III-4.

Cooling/Stabilization Pond

Wastewater quality for various treatment levels is given in Table 1.

Pond detention times are computed on a net effluent basis. (Net effluent = wastewater influent - evaporation + precipitation.) Effluent dissolved solids is given by influent concentration X (influent flow/net effluent flow).

To compute sludge build-up, it is assumed that 1 lb. of SS will produce 1 lb. of sludge and that 1 lb. of soluble BOD would produce 1 lb. of the sludge (6). A sludge moisture content of 95% and a specific gravity of the sludge solids of 1.3 were also used.

Costs of 30 mgd primary and secondary (activated sludge) treatment plants are taken from Smith (46).

TABLE 1
WASTEWATER CHARACTERISTICS

	Raw Wastewater	Primary Effluent	Secondary Effluent
Ultimate BOD (mg/l)	200	120	25
SS, Suspended Solids (mg/l)	200	60	25
DS, Dissolved Solids (mg/l)	200	200	200
Total Nitrogen (mg/l)	30	30	20
Total Phosphorus (mg/l)	15	13	10
pH	7	7	7

C. IRRIGATION OF ARGICULTURAL CROPS WITH WASTEWATER

A general procedure for determining nitrogen losses from land disposal areas has been developed (66). With some modification, this procedure is applied to wastewater irrigation on Suffolk County soils. These soils are well drained and have very small amounts of natural organic material or clay. A wastewater nitrogen content of 20 mg/l is assumed (Secondary effluent, Table 1). Suffolk County has a mean freeze-free period from mid-April to the end of October (64). This will permit a spray irrigation period of seven months (April-October), with storage of wastewater during the other five months. The application period is divided into a crop growing season segment (May-September) and pre and post growing seasons (April and October), and application rates are determined for each time segment.

A wastewater nitrogen content of 20 mg/l will result in a nitrogen application rate of 4.5 lb/in of irrigation water. The total nitrogen applied in each time segment is as follows: (lb/ac)

April:	19.5 Y
May-Sept:	99 X
October:	20 Y

where

Y = Irrigation rate in April and October (in/wk)

X = Irrigation rate during crop growing season: May-Sept. (in/wk)

If N_C = nitrogen removed by crop growth (lb/ac) then nitrogen available for loss in seepage water (and contamination of ground water) in lb/ac is:

$$99X + 39.5Y - N_C$$

The amount of water entering the water table in inches is:

$$P + 21.8X + 8.7Y - ET$$

Where

P = annual precipitation (in)

ET = annual evapotranspiration (in)

The average concentration of nitrogen in the seepage water or water entering the water table is given in mg/l as:

$$\frac{4.4\ (99X + 39.5Y - N_C}{P + 21.8X + 8.7Y - ET}$$

Average precipitation and evapotranspiration is 46 in. and 22 in. for the Suffolk County area (15).

Crop uptake of nitrogen (N_C) is estimated for potatoes, sod, cabbage and cauliflower (64, 67, 68, 69) as follows: Potatoes - 180 lb/ac, sod - 180 lb/ac, cabbage - 150 lb/ac, and cauliflower - 150 lb/ac.

In order to limit average nitrogen concentrations in seepage water to no more than 10 mg/l (assuming all nitrogen is converted to nitrate) maximum irrigation rates are determined for each crop and are reported in Table IV - I. These rates are subsequently used to estimate the required land areas given in Table IV - 2.

Ground water recharge is computed as the difference between the total wastewater application and the consumptive water deficit for the crop. The latter is the crop water needs (evapotranspiration) which cannot be met by growing season precipitation and is estimated at 4.6 in or 0.125 million gallons per acre. This compares with a 1954-1964 average irrigation application of 0.195 million gallons per year (irrigation is generally somewhat in excess of water deficits) for Suffolk County (15).

As an example, with a wastewater flow of 50 mgd, 6400 acres of potatoes could be irrigated (Table IV-2). Total irrigation is 18,250 million gallons, of which 6400 (0.125) = 800 million gallons would be used by the crop and the remaining 17,450 million gallons would recharge ground water at an average rate of 17,450/365 = 47.8 mgd.

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